UNIVERSIDADE FEDERAL DE CIÊNCIAS DA SAÚDE DE PORTO ALEGRE – UFCSPA

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA SAÚDE

Alexandre Severo do Pinho

Utilização de *Smartphones* na Avaliação do Equilíbrio Postural Através de Sensores Inerciais

Porto Alegre
2019

Alexandre Severo do Pinho

Utilização de *Smartphones* na Avaliação do Equilíbrio Postural Através de Sensores Inerciais

Tese submetida ao Programa de Pós-Graduação em Ciências da Saúde da Universidade Federal de Ciências da Saúde de Porto Alegre como requisito para a obtenção do grau de Doutor.

Orientadora: Prof.ª Dra. Aline de Souza Pagnussat
Coorientador: Prof. Dr. Ewald Max Hennig

Porto Alegre
2019

Catalogação na Publicação

Pinho, Alexandre Severo
Utilização de Smartphones na Avaliação do Equilíbrio Postural Através de Sensores Inerciais / Alexandre Severo Pinho. -- 2019.
98 f. : 30 cm.

Tese (doutorado) -- Universidade Federal de Ciências da Saúde de Porto Alegre, Programa de Pós-Graduação em Ciências da Saúde, 2019.

Orientador(a): Aline de Souza Pagnussat ; coorientador(a): Ewald Max Hennig.

1. Equilíbrio postural. 2. acelerometria. 3. smartphone. 4. saúde móvel. 5. acidentes por quedas. I. Título.

Sistema de Geração de Ficha Catalográfica da UFCSPA com os dados fornecidos pelo(a) autor(a).

REPÚBLICA FEDERATIVA DO BRASIL
MINISTÉRIO DA EDUCAÇÃO

UFCSPA

UNIVERSIDADE FEDERAL DE CIÊNCIAS DA SAÚDE DE PORTO ALEGRE

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA SAÚDE

TESE DE DOUTORADO

Título: "Utilização de smartphones na avaliação do equilíbrio postural através de sensores inerciais".

Autor: Alexandre Severo do Pinho
Orientadora: Profª. Aline de Souza Pagnussat
Coorientador: Prof. Ewald Max Hennig

Banca Examinadora

Profª. Eliana Márcia Da Ros Wendland	**UFCSPA**
Prof. Marcelo Faria Silva	**UFCSPA**
Profª. Janice Luisa Lukrafka Tartari	**UFCSPA**
Profª. Graciele Sbruzzi	**UFRGS**

PARECER DA BANCA
(descrição obrigatória)

As sugestões da banca devem ser discutidas com os orientadores.

(X) Aprovado ( ) Reprovado

Porto Alegre, 25 de outubro de 2019.

Profª. Eliana Márcia Da Ros Wendland
CPF: 594.981.270-53

Prof. Marcelo Faria Silva
CPF: 511.291.490-91

Profª. Janice Luisa Lukrafka Tartari
CPF: 89.117.797.20-00

Profª. Graciele Sbruzzi
CPF: 009.725.000-49

Dedico este momento aos meus maiores mestres... A professora da Aldeia Infantil S.O.S que me alfabetizou, Maria Inez Pimentel Severo (minha mãe), em memória ao professor rural João Luiz do Pinho (meu pai) e ainda, a minha avó Maria Luiza Moreira Pimentel, letrada apenas na bondade!

AGRADECIMENTOS

É difícil ser objetivo e reconhecer quem deveria ou não fazer parte desta seção "impressa" de agradecimentos. Este é um grande momento, mas valorizo muito também os pequenos momentos e aprendizados que a convivência no dia-a-dia nos proporciona, por que acredito que é o que nos faz exercitar verdadeiramente a nossa capacidade de evoluir pelas experiências e pode ou não fazer da nossa existência algo prazeroso e significativo. Por isso agradeço a todos os que se sintam parte da minha trajetória e que compartilharam de alguma forma para esse meu "processo de doutoramento".

À minha Mãe, corajosa e perseverante. Não iria tão longe sem tua fé e teus incentivos... "Sem medo de errar e recomeçar, quantas vezes forem necessárias..." e aqui estamos!

À Laura e Luísa, por estarem sempre ao meu lado, obrigado pelo amor incondicional de vocês! Cristina, gracias pelo suporte e por manter a família unida enquanto era possível... por todo teu esforço e agora por me ajudar a eu me manter presente!

Gratidão a todos os meus amigos, por estarem sempre por perto no "quando e aonde" foi preciso... Gut, Duda, Rodrigo, Tarta, Vivi, Pêpe, Rê, Guigui, Lucky... Aos meus parceiros de vôlei! Por estarem "lá" também, inclusive nas coletas de dados!!!

Agradeço ao Professor Milton Antonio Zaro, um querido amigo, sem dúvida meu maior exemplo de educador... um Samurai incansável!! me sinto grato e muito mais, um privilegiado por dividires teu tempo, tuas ideias e saberes em uma convivência descontraída e permeada de arte, música, ensinamentos, paciência e respeito mútuos... tu és responsável por despertar muito do que há "de ciência" em mim... foram muitas histórias e estórias! Ave, professor!

Ao Dr. Luiz Antonio Peroni e a Viviane de Brito Silva, agradeço pelas oportunidades de aprendizado ao longo de minha formação e como exemplo de profissionais. Um saudoso afeto. Um "lamento", também!

À Ana Paula Salazar, obrigado pelo carinho e por me ouvir pacientemente!

Aos colegas do grupo de pesquisa GNeR, em especial para a Maira, Camila, Ritchele, Giulia, Babi, Pati, Carol, Kátia, Elren... desde início do caminho, até agora! Gracias pelo convívio!!!

Aos funcionários da Pós-Graduação da UFCSPA, o meu sincero agradecimento, em especial a Cris, Dani, Maristela e Giovana, secretárias que pacientemente me auxiliaram nas demandas do curso, sempre educadas e dispostas.

Ao Prof. Marcelo Faria Silva e ao Prof. Rodrigo Della Méa Plentz por me receberem na Universidade antes mesmo do meu ingresso no doutorado. Tive o privilégio de colaborar e conhecer pessoas que me são muito queridas, tanto docentes como discentes do curso de fisioterapia, e demais alunos dos grupos de pesquisa e da pós-graduação. No laboratório do movimento humano, foram alguns anos com a presença da Milena e da Letícia em uma harmoniosa parceria de trabalho.

Agradeço também, quer por sua colaboração, ensinamentos ou pelo seu exemplo, aos Professores Leonardo Alexandre Peyré-Tartaruga, Matilde Achaval Elena, Alberto Antônio Rasia Filho, Lino Pinto de Oliveira Júnior, Janice Luisa Lukrafka Tartari, Luís Henrique Telles da Rosa, Pedro Dal Lago, Cláudio Osmar Pereira Alexandre, Ana Carolina Ribeiro Teixeira, Ana Carolina da Costa e

Fonseca, Cleidilene Ramos Magalhães, Aline Aver Vanin, Adriana Maisonnave Raffone, Graciele Sbruzzi, Flávia Gomez Martinez, Jefferson Loss e Clarice Sperotto dos Santos Rocha.

Agradeço aos professores que gentilmente se dispuseram a avaliar e contribuir com este trabalho em particular à relatora, Profa. Eliana Márcia Da Ros Wendland.

Ao Professor Tiago Becker e a estatística Cristiane Bündchen obrigado pelo auxílio na fase de processamento e análise dos dados.

Ao Professor Aluisio Octavio Vargas Avila e demais colegas do IBTEC, sou grato pelas oportunidades de aprendizado e espírito de compartilhamento do conhecimento que sempre permeou nossa relação... agradeço também pelo fundamental empréstimo da instrumentação utilizada no estudo 2.

Ao Professor Mário Cesar Andrade, da UDESC - mesmo que longe, agradeço pelos seus ensinamentos em biomecânica e sua influência em minha formação como pesquisador.

Ao Maestro Marcelo Rabello dos Santos, agradeço pelos momentos de inspiração em uma convivência prazerosa, leve e criativa junto ao coral da UFCSPA, agradeço ainda pela disponibilidade e auxílio na divulgação do projeto de pesquisa entre os coralistas (aos quais também sou muito grato!).

Agradeço a todos aqueles colegas, professores e funcionários que fizeram da minha estada nesta Universidade uma experiência agradável de aprendizado e crescimento.

Ao Professor Ewald Max Hennig, agradeço os ensinamentos do "mais brasileiro dos pesquisadores estrangeiros" que tivemos o privilégio em dividir experiências. (Thanks for sharing your time and knowledge with us! the most Brazilian foreign researcher! Vielen Dank Lehrer!).

Um agradecimento especial à professora Antoinette Domingo que me recebeu no seu laboratório em San Diego no período sanduíche (Thanks for accepting me in your lab and not less for the "scientific reasoning" mention!)

Aline. Agradeço pela paciência, pelas oportunidades, por sempre me deixar voar e então "me trazer de volta até o chão, carinhosamente..." (nos meus vários momentos de devaneio...). Sempre me identifiquei muito com tua vontade de aprender e tuas habilidades de ensinar, admiro tuas atitudes, tua postura, tua forma positiva no enfrentamento dos problemas (e simplicidade na resolução!) sempre com um olhar à frente... ponderada e educada! valorizo muito termos estado juntos durante esta minha formação... "te levarei" comigo! Muito obrigado Boss!

Aos alunos de graduação e pós com quem tive oportunidade de colaborar e também a todos os "meus" alunos e atletas! obrigado pelo aprendizado e confiança!

Aos voluntários que gentilmente aceitaram participar deste estudo, o meu muito obrigado!

Agradeço a CAPES pelo apoio financeiro e concessão de bolsa de estudos para o doutoramento e para o Programa de Doutorado Sanduíche no Exterior e à Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS) pelo apoio financeiro e viabilização de parte deste trabalho.

“Satisfaction lies in the effort, not in the attainment; full effort is full victory.”

Mahatma Gandhi

“It is exactly worthlessness to not be useful to anyone.”

René Descartes

“Se a educação sozinha não transforma a sociedade, sem ela tampouco a sociedade muda”.

Paulo Freire

RESUMO

O número de quedas na população idosa tem estimulado pesquisadores ao desenvolvimento de avaliações de equilíbrio mais efetivas. A tecnologia celular é uma alternativa promissora pelo seu baixo custo e facilidade de uso, no entanto, a validação das medidas de seus sensores necessita maiores investigações para dar suporte ao uso de aplicativos como ferramentas para avaliação clínica do equilíbrio postural. Na presente tese, foram desenvolvidos dois estudos que investigaram a possibilidade de uso da tecnologia de sensores inerciais de *Smartphones* na avaliação do equilíbrio. Verificou-se através de uma revisão sistemática da literatura, que apesar desta tecnologia ser utilizada para avaliar tarefas de estabilidade, estudos mais aprofundados são necessários para que esta técnica tenha sua acurácia comprovada. A metodologia dos artigos selecionados não permite adequada reprodutibilidade e a qualidade dos trabalhos foi considerada de fraca a moderada. Deste estudo originou-se a metodologia do segundo artigo, que verificou a acuidade das medidas de aceleração de 33 indivíduos idosos em tarefas de equilíbrio, medidas por um *Smartphone* e comparadas às medidas de um acelerômetro comercial e uma plataforma de força. A correlação e a concordância entre os valores de aceleração foram consideradas altas entre os instrumentos inerciais (*Smartphone* x Acelerômetro). Quando comparados os valores de aceleração aos parâmetros de descrição do equilíbrio (*Smartphone* x Plataforma de Força), as correlações foram consideradas de fracas a moderadas. Foi possível concluir que a aceleração, mensurada pelo *Smartphone* pode ser uma ferramenta para a avaliação do equilíbrio, desde que utilizado adequado processamento de dados.

Palavras-chave: Equilíbrio postural; acelerometria; *smartphone*; saúde móvel; acidentes por quedas

ABSTRACT

The number of falls in the elderly population has encouraged researchers to develop more effective balance assessments. Mobile technology is a promising alternative for its low cost and ease of use, however, the validation of its sensor measurements needs further investigation to support the routine use of applications as tools for clinical evaluation of postural balance. In the present thesis, two studies were developed to investigate the possibility of using the inertial sensor technology of Smartphones in the postural balance evaluation. It was verified through a systematic review of the literature, that although this technology is used to evaluate different stability tasks, further studies are still necessary for this technique to have its proven accuracy. The methodology of most of the selected articles does not allow adequate reproducibility, and the quality of the works was considered to be poor to moderate. This study originated the methodology of the second article, which sought to verify the accuracy of acceleration measures of 33 individuals over 60 years performing balance tasks by comparing data between a Smartphone, a commercial accelerometer, and a force platform. Correlation and agreement between acceleration values were considered high among inertial instruments (Smartphone x Accelerometer). The acceleration values in the evaluated tasks were also compared with the center of pressure oscillation variables measured by the force platform. The correlation between the measurements was considered weak to moderate when compared to the main parameters of the postural balance measured by the oscillations of the center of pressure. It was possible to conclude that the acceleration, measured by the Smartphone used in this analysis, can be a tool for balance evaluation, provided that adequate data processing is used.

Keywords: Postural balance; Accelerometry ; Smartphone ; mHealth; Accidental Falls.

LISTA DE FIGURAS

Estudo 1

Estudo 2

LISTA DE TABELAS

Estudo 1

Estudo 2

LISTA DE SIGLAS E ABREVIAÇÕES EM INGLÊS

AP = anteroposterior

Acc = Accelerometer

BESS = Balance error scoring system

BMI = Body mass index

cm = centimeter

COG = center of gravity

COM = center of mass

COP = center of pressure

FES= Falls Efficacy Scale

Hz = Hertz

ICC = intraclass correlation coefficient

IMU = inertial measurement units

kg = kilograms

LOS = functional stability limit test

MEMS = Micro-Electro-Mechanical Systems

ML = mediolateral

mm = milimiter

mm^2 = squared milimetre

Sumário

1. CONTEXTUALIZAÇÃO

O estudo do equilíbrio tem sido justificado pelo aumento da expectativa de vida e do risco de quedas na população idosa (FOREMAN et al., 2018). Segundo a Organização Mundial de Saúde, a queda é a segunda causa principal de mortes acidentais ou não intencionais em todo o mundo. Mais de 37,3 milhões de quedas são graves o suficiente para exigir atenção médica, e há estimativa de 646 mil pessoas morrem todos os anos, das quais mais de 80% estão em países de baixa e média renda ("Falls Fact sheet Reviewed January 2018", 2018). Aproximadamente 30% dos adultos acima de 65 anos caem todos os anos de maneira a necessitar cuidados médicos e internações. Quedas são eventos tão comuns em determinadas populações que, nos casos de menor gravidade, cerca de um terço dos afetados não procura assistência médica (STEVENS et al., 2012), contudo, estudos indicam taxas de mortalidade de 20% nos primeiros três meses após quedas graves, e cerca de 12% nos primeiros 30 dias (MANGRAM; DZANDU, 2016).

As consequências das quedas relacionadas a essas estatísticas têm estimulado pesquisadores ao desenvolvimento de estratégias de prevenção, concentradas em protocolos de treinamento e avaliações de equilíbrio mais efetivas (FABRE et al., 2010; LEE; GELLER; STRASSER, 2013; VAN DER KOOIJ; VAN ASSELDONK; VAN DER HELM, 2005). Várias causas são atribuídas às quedas na população idosa. Características funcionais como fraqueza muscular, amplitude de movimento limitada, baixa capacidade de respostas às informações das vias proprioceptivas, déficits visuais e vestibulares são descritos como críticos para o controle motor adequado (ALONSO et al., 2015; KARUKA; SILVA; NAVEGA, 2011; LIN et al., 2008; MANCHESTER et al., [s.d.]).

Com o envelhecimento, a perda da força, a perda da massa muscular e a redução da mobilidade são de fundamental importância na execução de tarefas diárias e têm sido reportadas como principais fatores de risco "modificáveis" (MORELAND et al., 2004). A acuidade visual diminuída responde pela redução do

envio de informações relacionadas às referências espaciais, prejudicando a tomada de decisões para os ajustes posturais (NASHNER; BERTHOZ, 1978; OSOBA et al., 2019). Quanto às informações proprioceptivas de posição articular, da mesma forma, a redução do número de estruturas sensitivas como o fuso muscular e os órgãos tendinosos de Golgi, impedem respostas motoras adequadas de adaptação como em situações de variação de superfícies e oscilações rápidas do corpo. De maior interferência na manutenção da estabilidade em tarefas dinâmicas relativas às interações gravitacionais, disfunções vestibulares interferem nos padrões motores alterando a interpretação e adequação das informações captadas pelos sistemas visual e proprioceptivo (ALBERTSEN et al., 2017, p.; MANCHESTER et al., [s.d.]). Com o controle motor dos segmentos corporais alterado, há uma ingerência das estratégias motoras, prejudicando o processamento das informações e desencadeando respostas anômalas ou tardias de alinhamento e estabilidade corporal (HORAK, 2006; HORAK; NASHNER, 1986).

O equilíbrio pode ser classificado como a habilidade do indivíduo em manter o seu centro de massa (CM) dentro da base de suporte, uma área sobre a superfície que engloba os limites externos do contato dos pés e é dependente da distância entre os apoios plantares (POLLOCK et al., 2000; WINTER, 1995; WINTER et al., 1996). Uma região de estabilidade, de menor extensão, demarca os deslocamentos máximos em diferentes direções (NASHNER; MCCOLLUM, 1985; WINTER, 1995). A posição dos segmentos corporais e a relação do corpo no espaço, que permitem o indivíduo adaptar-se aos estímulos externos mantendo-se nestes limites, são baseadas em informações dos sistemas visual, somatossensorial e vestibular. O controle postural atua através de contrações musculares e de ajustes posturais provenientes dessas informações sensoriais que chegam ao Sistema Nervoso Central (HORAK, 2006; LEWIS MICHAEL NASHNER, 1970, 1970; POLLOCK et al., 2000).

As estratégias de tornozelo, do quadril e do passo, são os principais mecanismos de ações posturais utilizados no controle motor de equilíbrio quase-estático (HORAK; NASHNER, 1986). Em posição bipodal o torque nas articulações e em particular o produzido sobre a superfície de contato permite a estabilidade através de movimentos de pequena magnitude em indivíduos hígidos, onde as estratégias de tornozelo se tornam mais evidentes e são usualmente explicadas através de um modelo de pêndulo invertido (WINTER, 1995; WINTER et al., 1996). Este modelo reducionista representa adequadamente as oscilações anteriores e posteriores do corpo, principalmente quando observadas no plano sagital em que os membros inferiores se apresentam paralelos e unidos, mas perde sensibilidade em movimentos laterais(HORAK, 2006). Sua efetividade também se baseia no pressuposto da redução dos graus de liberdade de movimentos articulares de quadril, joelho e tronco em postura ortostática pelas menores perturbações apresentadas (MORASSO; CHERIF; ZENZERI, 2019; WINTER, 1995).

Nas estratégias de quadril, contrações de musculaturas envolvidas no dorso e membros inferiores regulam a posição do tronco alterando o CM, principalmente quando da extensão completa de joelhos. Essas são mais evidentes em situações de movimento de instabilidade dinâmica com mudanças de inclinação da superfície e redução da função articular do tornozelo por eventual rigidez, inclusive naquelas relacionadas por co-contrações atípicas como as de populações com doenças neurológicas (BROGLIO et al., 2009; WARNICA et al., 2014). A estratégia do passo é usualmente desencadeada por perturbações maiores quando as estratégias sem deslocamento são insuficientes para recuperar o equilíbrio e reposição do CM dos limites de estabilidade, e é frequentemente relacionada como último recurso para recuperar a estabilidade (HORAK; NASHNER, 1986; NASHNER; MCCOLLUM, 1985).

Para a avaliação do equilíbrio, métodos qualitativos e quantitativos são empregados para inferir informações sobre a estabilidade postural. Questionários e avaliações observacionais avaliam a capacidade de realizar tarefas de diferentes níveis de complexidade e estão entre os métodos clínicos subjetivos mais utilizados pela facilidade de aplicação e baixo custo (MANCINI; HORAK, 2010; SIBLEY et al., 2013).

O equilíbrio postural pode ser indiretamente mensurado através da descrição das oscilações de segmentos corporais em função de eixos e planos de movimento, geralmente associados a medidas dinamométricas (mensuração de forças aplicadas) em tarefas dinâmicas ou estáticas. Essas medidas permitem evidenciar as competências de cada sistema na estabilidade global do indivíduo (HOF, 2005; HUXHAM; GOLDIE; PATLA, 2001), representadas por variáveis cinéticas (forças associadas ao movimento) associadas às espaço-temporais (decorrentes da variação da posição no tempo, velocidade e aceleração) e descrevem, portanto, interações do corpo humano com o meio pela representação do comportamento do centro de massa (CM) e do centro de gravidade (CG) do indivíduo (BENDA; RILEY; KREBS, 1994; ROBERTSON et al., 2014). Estas medidas quantitativas observadas no CM, mais complexas e onerosas, apesar de ser melhor aplicada a corpos rígidos, são amplamente utilizadas em avaliações do movimento humano através de conceitos mecânicos, modelos matemáticos e da reconstrução espacial tridimensional (LAFOND; DUARTE; PRINCE, 2004).

Plataformas de força ou pressão podem ser utilizadas para medir o comportamento das forças resultantes das estratégias corporais e consequentemente a magnitude destas oscilações (BENDA; RILEY; KREBS, 1994; LAFOND; DUARTE; PRINCE, 2004; ROBERTSON et al., 2014). As Plataformas de força tridimensionais, consideradas “padrão ouro” na avaliação do equilíbrio, medem as forças de reação do solo, e independentemente da localização e do número de pontos de aplicação, fornecem uma força resultante aplicada sobre sua

superfície (BŁASZCZYK, 2016; MANSFIELD; INNESS, 2015). A localização deste vetor resultante se relaciona a uma área de contato ou a uma superfície de apoio sobre a plataforma e se denomina centro de pressão (COP). A localização do COP, portanto, é obtida através do cálculo das forças e momentos nos três eixos e é representada por parâmetros de oscilação nas direções anteroposterior e médio-lateral podendo ser descrita em função do tempo ou ainda analisadas quanto ao seu espectro de frequências destas oscilações (ROBERTSON et al., 2014). As magnitudes destes deslocamentos no domínio do tempo são mensuradas a partir de suas médias, desvios padrões, amplitudes, variâncias, mínimos e máximos. Estes parâmetros do COP quando relacionados à postura, apresentam padrões característicos em cada situação, seja ela normal ou patológica (BELL et al., 2011; BENDA; RILEY; KREBS, 1994; MORASSO; SPADA; CAPRA, 1999; PIZZIGALLI et al., 2016) e apresentam comportamentos oscilatórios correlacionáveis aos do CM e CG em situações de equilíbrio bipodal (BENDA; RILEY; KREBS, 1994; MORASSO; SPADA; CAPRA, 1999). O uso destes instrumentos para avaliar o equilíbrio tem se mostrado fundamental na orientação clínica auxiliando nas decisões dos profissionais da saúde no que diz respeito ao seguimento, estadiamento e reabilitação (DOHENY et al., 2012; FRANCHIGNONI et al., 2010; PAILLARD; NOÉ, 2015).

O modelo do pêndulo invertido, evidenciado pela estratégia do tornozelo, tem sido aplicado tanto com o uso de plataformas de força quanto por medidas de aceleração por sensores inerciais. Esses geralmente são fixados ao tronco, próximo ao CM do indivíduo (MORASSO; CHERIF; ZENZERI, 2019). Os sensores inerciais podem mensurar as acelerações nos três eixos, e quando combinados a giroscópios, fornecem informações da velocidade angular (MAYAGOITIA et al., 2002; MORRIS, 1973).

A estabilidade, portanto, pode ser expressa por diferentes parâmetros e variáveis que são mais ou menos sensíveis para descrever a normalidade ou

disfunções do equilíbrio. A caracterização destas variáveis é derivada de complexas técnicas de processamentos de sinais nos métodos tradicionais de análise do movimento (CHIARI et al., 2000; LAFOND; DUARTE; PRINCE, 2004; LIN et al., 2008; PIZZIGALLI et al., 2016; WINTER, 1995; ZATSIORSKY; DUARTE, 1999, 2000). O tempo demorado nas avaliações, o grau de complexidade das análises e os custos dos dispositivos tornam a interpretação dos resultados desafiadora e restrita à pesquisa acadêmica ou serviços privados dispendiosos (BARATTO et al., 2002; CLARK; RILEY, 2007).

Com a popularização de tecnologias interativas de informação como dispositivos eletrônicos portáteis ou "*Gadgets" (Smartphones, PDAs, handhelds, Tablets*), profissionais de saúde têm gradualmente incorporado em seu cotidiano o uso destes sensores no auxílio de suas tarefas (MORAL-MUNOZ et al., 2018). Particularmente, as recentes inovações técnicas dos *Microssistemas Integrados ou* "MEMS" (*micro-electro-mechanical systems*)*,* uma conjunção entre tecnologia de microeletrônica (nanotecnologia) e mecânica integrada (sensores mecânicos), melhorou sensivelmente a velocidade de processamento e precisão dos sensores motivando profissionais ao desenvolvimento de *softwares* e aplicativos na emergente área da "Saúde Digital" (mHealth) (DEL ROSARIO; REDMOND; LOVELL, 2015; DOBKIN; DORSCH, 2011; WONG et al., 2015).

A tecnologia utilizada pelos acelerômetros se baseia nos fenômenos físicos observados pelas leis de Newton sobre a força e a inércia e fornecem, a partir da energia mecânica captada por um transdutor (conversor), um sinal elétrico mensurável. Um sistema "massa-mola" embutido nestes sensores é sensível ao movimento na medida que uma aceleração proporcional é produzida pelo deslocamento desta "massa". Das medidas de aceleração destes equipamentos pode-se obter informações sobre a velocidade e a posição, com a utilização de métodos numéricos de integração (CHEN; BASSETT, 2005; FRIEDMAN et al., 2012; LUINGE; VELTINK, 2005).

Diferentes tipos de sensores inerciais, diferenciados por suas características de construção, estão acessíveis no mercado e os sistemas capacitivos são os mais utilizados para avaliação do equilíbrio por terem melhor reposta a baixas frequências e melhor sensibilidade para a caracterização de sistemas estáticos (CHEN; BASSETT, 2005). Estes sensores permitem inúmeras aplicações, pois a partir de medidas geradas pelo campo gravitacional, é possível descrever o ângulo de inclinação e a orientação dos dispositivos em relação ao plano vertical, característica comum utilizada na tecnologia de *Smartphones* e outros dispositivos móveis (LUINGE; VELTINK, 2005). Equipamentos classificados como “sensores vestíveis” (*wearable devices*) tem sido empregado em pesquisas de análise do movimento humano tendo maior eficácia na descrição de atividades cíclicas de maior amplitude de movimento ou impacto (ALBERTS et al., 2015; DOBKIN; DORSCH, 2011; DOHENY et al., 2012; EKVALL HANSSON; TORNBERG, 2019; MA et al., 2016; NEVILLE; LUDLOW; RIEGER, 2015).

Para a avaliação do equilíbrio, sensores comerciais (acelerômetros comerciais) tiveram sua sensibilidade comprovada e acurácia comparável a outras técnicas de investigação em biomecânica (BŁASZCZYK, 2016; LEE; SUN, 2018; MAYAGOITIA et al., 2002; SEIMETZ et al., 2012). Na tecnologia da telefonia celular, pesquisas têm demonstrado a possibilidade de seu uso na área clínica (BUSIS, 2010; CAPELA et al., 2016; GALÁN-MERCANT et al., 2014; MCNAB; JAMES; ROWLANDS, 2011; MICKAN et al., 2014; WALTER; KOSY; COVE, 2013), mas a dificuldade de generalizar seus resultados em função de diferenças técnicas entre modelos celulares, da inconsistência de alguns protocolos propostos ou ainda da especificidade de determinadas populações avaliadas ainda restringem sua aplicação (PINHO et al., 2019). Portanto, alguns desafios precisam ser superados, como reduzir os erros de aproximação pelos métodos numéricos (“IMU Errors and Their Effects”, [s.d.]) e aproximar os resultados de avaliações quantitativas,

baseadas em conceitos físicos e matemáticos, ao entendimento de pacientes e profissionais da saúde tornando-os mais integrados e coerentes aos desfechos clínicos (HABIB et al., 2014; RUHE et al., 2014).

Algumas vantagens no uso de *Smartphones* e *gadgets* em avaliações podem ser destacadas: (a) o equipamento é relativamente mais acessível (b) avaliações em tempo real; (c) protocolos auto administrados; (d) *feedback* rápido e confiável; (e) aplicações amigáveis, relatórios e gráficos simplificados; (f) facilidade de divulgação dos resultados (compartilhamento), melhorando a comunicação e o vínculo entre paciente, profissionais de saúde e família; (g) facilidade de compreender e monitorar o acompanhamento, estimulando a adesão do paciente ao tratamento (DOBKIN; DORSCH, 2011). Por outro lado, é reconhecido que a aceitação do uso de novas tecnologias e, mais especificamente o uso de aplicativos pela população idosa ainda é baixa se comparada ao uso por indivíduos jovens, possivelmente a maior barreira a ser superada (MA; CHAN; CHEN, 2016). Mesmo que a utilização destas ferramentas possa ser direcionada aos profissionais da saúde, o uso por indivíduos leigos pressupõe o acesso, a familiarização e aceitação dos idosos ao uso dos Smartphones no dia-a-dia, o que deve ser considerado como um potencial entrave na disseminação desta tecnologia (FISCHER et al., 2014).

Embora essas ferramentas não sejam totalmente validadas, as perspectivas são evidentes, bem como a necessidade de questionar os pontos fortes e fracos das diferentes abordagens, uma demanda que surge naturalmente com uma nova ferramenta ou técnica de avaliação (CHUNG; SOANGRA; LOCKHART, 2014; HAN; LEE; LEE, 2016; KOSSE et al., 2015; OZINGA; ALBERTS, 2014; SHAH; ALEONG; SO, 2016; WHITNEY et al., 2011). No entanto, mais investigações são necessárias para dar suporte ao seu uso como uma ferramenta de rotina para avaliar e gerenciar os dados do equilíbrio corporal (DEL ROSARIO; REDMOND; LOVELL, 2015).

São indiscutíveis também as necessidades da população em risco de quedas de meios que auxiliem na prevenção destes eventos, potencializados ainda pela infraestrutura deteriorada das cidades e pelo baixo acesso à programas de saúde de qualidade. A morbidade resultante de acidentes por quedas repercute na qualidade de vida de indivíduos, reduzindo sua independência, influenciando na expectativa de vida de idosos, onerando orçamentos familiares e governamentais o que justifica a necessidade do desenvolvimento de métodos de prevenção de baixo custo, de melhor eficácia e uso clínico mais abrangente.

Sendo assim, na presente tese, foram desenvolvidos dois estudos que investigaram a possibilidade de se utilizar a tecnologia de sensores inerciais de telefones celulares na avaliação do equilíbrio. O primero artigo, intitulado: "*Can we rely on mobile devices and other gadgets to assess the postural balance of healthy individuals? A systematic review*" teve como foco principal buscar evidências sobre a capacidade dessa tecnologia em avaliar o equilíbrio de sujeitos hígidos. As potencialidades e as limitações das metodologias foram destacadas com a intenção de fornecer aos leitores informações básicas, porém essenciais, na identificação dos métodos mais convenientes para a utilização da técnica de sensores inerciais para a avaliação do equilíbrio postural. O segundo artigo, intitulado: "*Smartphones acceleration measurements for balance assessment*", é um estudo transversal que compara as medidas de aceleração de um *Smartphone* com um acelerômetro comercial considerado "padrão ouro" e ainda correlaciona dados de aceleração com parâmetros de equilíbrio avaliados com uma plataforma de força tridimensional, "padrão ouro" para as medidas de controle postural. O objetivo foi fornecer subsídios que sustentassem o uso de sensores inerciais de um *Smartphone* para esta finalidade e resultados experimentais sobre o processamento dos dados que justificassem o desenvolvimento de um aplicativo para a avaliação do equilíbrio. Os estudos estão apresentados a seguir, em formato de artigo científico, de acordo com as normas dos periódicos selecionados.

REFERÊNCIAS

ALBERTS, J. L. et al. **Using Accelerometer and Gyroscopic Measures to Quantify Postural Stability.** Journal of Athletic Training, v. 50, n. 6, p. 578–588, 2 jun. 2015.

ALBERTSEN, I. M. et al. **Postural stability in young healthy subjects – Impact of reduced base of support, visual deprivation, dual tasking.** Journal of Electromyography and Kinesiology, v. 33, p. 27–33, abr. 2017.

ALONSO, A. C. et al. **Relation between the Sensory and Anthropometric Variables in the Quiet Standing Postural Control: Is the Inverted Pendulum Important for the Static Balance Control?** BioMed Research International, v. 2015, 2015.

BARATTO, L. et al. **A new look at posturographic analysis in the clinical context: sway-density versus other parameterization techniques**. Motor Control, v. 6, n. 3, p. 246–270, jul. 2002.

BELL, D. R. et al. **Systematic Review of the Balance Error Scoring System**. Sports Health, v. 3, n. 3, p. 287–295, maio 2011.

BENDA, B. J.; RILEY, P. O.; KREBS, D. E. **Biomechanical relationship between center of gravity and center of pressure during standing**. IEEE Transactions on Rehabilitation Engineering, v. 2, n. 1, p. 3–10, 1994.

BŁASZCZYK, J. W. **The use of force-plate posturography in the assessment of postural instability**. Gait & Posture, v. 44, p. 1–6, fev. 2016.

BROGLIO, S. P. et al. **The influence of ankle support on postural control**. Journal of science and medicine in sport, v. 12, n. 3, p. 388–392, maio 2009.

BUSIS, N. **Mobile Phones to Improve the Practice of Neurology**. Neurologic Clinics, v. 28, n. 2, p. 395–410, maio 2010.

CAPELA, N. A. et al. **Evaluation of a smartphone human activity recognition application with able-bodied and stroke participants**. Journal of NeuroEngineering and Rehabilitation, v. 13, 20 jan. 2016.

CHEN, K. Y.; BASSETT, D. R. **The Technology of Accelerometry-Based Activity Monitors: Current and Future**. Medicine & Science in Sports & Exercise, v. 37, n. Supplement, p. S490–S500, nov. 2005.

CHIARI, L. et al. **An improved technique for the extraction of stochastic parameters from stabilograms**. Gait & Posture, v. 12, n. 3, p. 225–234, dez. 2000.

CHUNG, C. C.; SOANGRA, R.; LOCKHART, T. E. **Recurrence Quantitative Analysis of Postural Sway using Force Plate and Smartphone**. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, v. 58, n. 1, p. 1271–1275, set. 2014.

CLARK, S.; RILEY, M. A. **Multisensory information for postural control: sway-referencing gain shapes center of pressure variability and temporal dynamics**. Experimental Brain Research, v. 176, n. 2, p. 299–310, jan. 2007.

DEL ROSARIO, M.; REDMOND, S.; LOVELL, N. **Tracking the Evolution of Smartphone Sensing for Monitoring Human Movement**. Sensors, v. 15, n. 8, p. 18901–18933, 31 jul. 2015.

DOBKIN, B. H.; DORSCH, A. **The Promise of mHealth: Daily Activity Monitoring and Outcome Assessments by Wearable Sensors**. Neurorehabilitation and neural repair, v. 25, n. 9, p. 788–798, 2011.

DOHENY, E. P. et al. **Displacement of centre of mass during quiet standing assessed using accelerometry in older fallers and non-fallers**. 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). San Diego, CA: IEEE, ago. 2012 Disponível em: <http://ieeexplore.ieee.org/document/6346670/>. Acesso em: 1 nov. 2018

EKVALL HANSSON, E.; TORNBERG, Å. **Coherence and reliability of a wearable inertial measurement unit for measuring postural sway**. BMC Research Notes, v. 12, 2 abr. 2019.

FABRE, J. M. et al. **Falls Risk Factors and a Compendium of Falls Risk Screening Instruments**. Journal of GERIATRIC Physical Therapy, v. 33, n. 4, p. 14, 2010.

FISCHER, S. H. et al. **Acceptance and Use of Health Information Technology By Community-Dwelling Elders**. International journal of medical informatics, v. 83, n. 9, p. 624–635, set. 2014.

FOREMAN, K. J. et al. **Forecasting life expectancy, years of life lost, and all-cause and cause-specific mortality for 250 causes of death: reference and alternative scenarios for 2016–40 for 195 countries and territories**. The Lancet, v. 392, n. 10159, p. 2052–2090, nov. 2018.

FRANCHIGNONI, F. et al. **Using psychometric techniques to improve the Balance Evaluation Systems Test: the mini-BESTest**. Journal of Rehabilitation Medicine, v. 42, n. 4, p. 323–331, 2010.

FRIEDMAN, A. et al. **Estimation of accelerometer orientation for activity recognition**. Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE. Anais IEEE, 2012 Disponível em: http://ieeexplore.ieee.org/abstract/document/6346368/> Acesso em: 7 jul. 2017

GALÁN-MERCANT, A. et al. **Reliability and criterion-related validity with a smartphone used in timed-up-and-go test**. BioMedical Engineering OnLine, v. 13, 2 dez. 2014.

HABIB, M. et al. **Smartphone-Based Solutions for Fall Detection and Prevention: Challenges and Open Issues**. Sensors, v. 14, n. 4, p. 7181–7208, 22 abr. 2014.

HAN, S.; LEE, D.; LEE, S. **A study on the reliability of measuring dynamic balance ability using a smartphone**. Journal of physical therapy science, v. 28, n. 9, p. 2515–2518, 2016.

HOF, A. L. **Comparison of three methods to estimate the center of mass during balance assessment**. Journal of Biomechanics, v. 38, n. 10, p. 2134–2135, out. 2005.

HORAK, F. B. **Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls?** Age and Ageing, v. 35, n. suppl_2, p. ii7–ii11, 1 set. 2006.

HORAK, F. B.; NASHNER, L. M. **Central programming of postural movements: adaptation to altered support-surface configurations**. Journal of Neurophysiology, v. 55, n. 6, p. 1369–1381, jun. 1986.

HUXHAM, F. E.; GOLDIE, P. A.; PATLA, A. E. **Theoretical considerations in balance assessment**. Australian Journal of Physiotherapy, v. 47, n. 2, p. 89–100, 2001.

IMU Errors and Their Effects. , [s.d.]. Disponível em: https://www.novatel.com/assets/Documents/Bulletins/APN064.pdf > Acesso em: > Acesso em: out/2018

KARUKA, A. H.; SILVA, J. A. M. G.; NAVEGA, M. T. **Analysis of agreement of assessment tools of body balance in the elderly**. Revista Brasileira De Fisioterapia (São Carlos, São Paulo, Brazil), v. 15, n. 6, p. 460–466, dez. 2011.

KOSSE, N. M. et al. **Validity and Reliability of Gait and Postural Control Analysis Using the Tri-axial Accelerometer of the iPod Touch**. Annals of Biomedical Engineering, v. 43, n. 8, p. 1935–1946, ago. 2015.

LAFOND, D.; DUARTE, M.; PRINCE, F. **Comparison of three methods to estimate the center of mass during balance assessment**. Journal of Biomechanics, v. 37, n. 9, p. 1421–1426, set. 2004.

LEE, C.-H.; SUN, T.-L. **Evaluation of postural stability based on a force plate and inertial sensor during static balance measurements**. Journal of Physiological Anthropology, v. 37, 13 dez. 2018.

LEE, J.; GELLER, A. I.; STRASSER, D. C. **Analytical Review: Focus on Fall Screening Assessments**. PM&R, v. 5, n. 7, p. 609–621, jul. 2013.

LEWIS MICHAEL NASHNER. **sensory feedback in human posture control**, 4 maio 1970.

LIN, D. et al. **Reliability of COP-based postural sway measures and age-related differences**. Gait & Posture, v. 28, n. 2, p. 337–342, ago. 2008.

LUINGE, H. J.; VELTINK, P. H. **Measuring orientation of human body segments using miniature gyroscopes and accelerometers**. Medical & Biological Engineering & Computing, v. 43, n. 2, p. 273–282, abr. 2005.

MA, C. et al. **Balance Improvement Effects of Biofeedback Systems with State-of-the-Art Wearable Sensors: A Systematic Review**. Sensors, v. 16, n. 4, p. 434, 25 mar. 2016.

MA, Q.; CHAN, A. H. S.; CHEN, K**. Personal and other factors affecting acceptance of smartphone technology by older Chinese adults**. Applied Ergonomics, v. 54, p. 62–71, maio 2016.

MANCHESTER, D. et al. **Visual, Vestibular and Somatosensory Contributions to Balance Control in the Older Adult**. p. 10, [s.d.].

MANCINI, M.; HORAK, F. B. **The relevance of clinical balance assessment tools to differentiate balance deficits**. European journal of physical and rehabilitation medicine, v. 46, n. 2, p. 239, 2010.

MANGRAM, A.; DZANDU, J. **Why Elderly Patients with Ground Level Falls Die Within 30 Days And Beyond?** Journal of Gerontology & Geriatric Research, v. 05, n. 02, 2016.

MANSFIELD, A.; INNESS, E. L. **Force Plate Assessment of Quiet Standing Balance Control: Perspectives on Clinical Application within Stroke Rehabilitation**. Rehabilitation Process and Outcome, v. 4, p. RPO.S20363, jan. 2015.

MAYAGOITIA, R. E. et al. **Standing balance evaluation using a triaxial accelerometer**. Gait & Posture, v. 16, n. 1, p. 55–59, ago. 2002.

MCNAB, T.; JAMES, D. A.; ROWLANDS, D. **iPhone sensor platforms: Applications to sports monitoring**. Procedia Engineering, v. 13, p. 507–512, 2011.

MICKAN, S. et al. **Use of handheld computers in clinical practice: a systematic review**. BMC Medical Informatics and Decision Making, v. 14, p. 56, 6 jul. 2014.

MORAL-MUNOZ, J. A. et al. **Smartphone Applications to Perform Body Balance Assessment: a Standardized Review**. Journal of Medical Systems, v. 42, n. 7, jul. 2018.

MORASSO, P.; CHERIF, A.; ZENZERI, J. **Quiet standing: The Single Inverted Pendulum model is not so bad after all**. PLoS ONE, v. 14, n. 3, 21 mar. 2019.

MORASSO, P. G.; SPADA, G.; CAPRA, R. **Computing the COM from the COP in postural sway movements**. Human Movement Science, v. 18, n. 6, p. 759–767, 1 dez. 1999.

MORELAND, J. D. et al. **Muscle Weakness and Falls in Older Adults: A Systematic Review and Meta-Analysis**. Journal of the American Geriatrics Society, v. 52, n. 7, p. 1121–1129, jul. 2004.

MORRIS, J. R. W. **Accelerometry - A technique for the measurement of human body movements**. Journal of Biomechanics, v. 6, n. 6, p. 729–736, nov. 1973.

NASHNER, L.; BERTHOZ, A. **Visual contribution to rapid motor responses during postural control**. Brain Research, v. 150, n. 2, p. 403–407, jul. 1978.

NASHNER, L. M.; MCCOLLUM, G. **The organization of human postural movements: A formal basis and experimental synthesis**. Behavioral and Brain Sciences, v. 8, n. 1, p. 135–150, mar. 1985.

NEVILLE, C.; LUDLOW, C.; RIEGER, B. **Measuring postural stability with an inertial sensor: validity and sensitivity**. Medical Devices: Evidence and Research, p. 447, nov. 2015.

OSOBA, M. Y. et al. **Balance and gait in the elderly: A contemporary review**. Laryngoscope Investigative Otolaryngology, v. 4, n. 1, p. 143–153, 4 fev. 2019.

OZINGA, S. J.; ALBERTS, J. L. **Quantification of postural stability in older adults using mobile technology**. Experimental Brain Research, v. 232, n. 12, p. 3861–3872, dez. 2014.

PAILLARD, T.; NOÉ, F. **Techniques and Methods for Testing the Postural Function in Healthy and Pathological Subjects**. BioMed Research International, v. 2015, 2015.

PINHO, A. S. et al. **Can We Rely on Mobile Devices and Other Gadgets to Assess the Postural Balance of Healthy Individuals? A Systematic Review**. Sensors (Basel, Switzerland), v. 19, n. 13, 5 jul. 2019.

PIZZIGALLI, L. et al. **The contribution of postural balance analysis in older adult fallers: A narrative review**. Journal of Bodywork and Movement Therapies, v. 20, n. 2, p. 409–417, abr. 2016.

POLLOCK, A. S. et al. **What is balance?** Clinical Rehabilitation, v. 14, n. 4, p. 402–406, ago. 2000.

ROBERTSON, D. G. E. et al. **Research methods in biomechanics**. Second edition ed. Champaign, Illinois: Human Kinetics, 2014.

RUHE, A. et al. **Assessing postural stability in the concussed athlete: what to do, what to expect, and when.** Sports health, v. 6, n. 5, p. 427–433, 2014.

SEIMETZ, C. et al. **A comparison between methods of measuring postural stability: force plates versus accelerometers**. Biomedical sciences instrumentation, v. 48, p. 386, 2012.

SHAH, N.; ALEONG, R.; SO, I. **Novel Use of a Smartphone to Measure Standing Balance**. JMIR Rehabilitation and Assistive Technologies, v. 3, n. 1, p. e4, 29 mar. 2016.

SIBLEY, K. M. et al. **Clinical balance assessment: perceptions of commonly-used standardized measures and current practices among physiotherapists in Ontario, Canada**. Implementation Science, v. 8, n. 1, dez. 2013.

STEVENS, J. A. et al. **Gender Differences in Seeking Care for Falls in the Aged Medicare Population**. American Journal of Preventive Medicine, v. 43, n. 1, p. 59–62, jul. 2012.

VAN DER KOOIJ, H.; VAN ASSELDONK, E.; VAN DER HELM, F. C. T. **Comparison of different methods to identify and quantify balance control**. Journal of Neuroscience Methods, v. 145, n. 1–2, p. 175–203, jun. 2005.

WALTER, R.; KOSY, J. D.; COVE, R. **Inter- and intra-observer reliability of a smartphone application for measuring hallux valgus angles**. Foot and Ankle Surgery, v. 19, n. 1, p. 18–21, mar. 2013.

WARNICA, M. J. et al. **The influence of ankle muscle activation on postural sway during quiet stance**. Gait & Posture, v. 39, n. 4, p. 1115–1121, abr. 2014.

WHITNEY, S. L. et al. **A comparison of accelerometry and center of pressure measures during computerized dynamic posturography: A measure of balance**. Gait & posture, v. 33, n. 4, p. 594–599, abr. 2011.

WINTER, D. A. **Human balance and posture control during standing and walking**. Gait & posture, v. 3, n. 4, p. 193–214, 1995.

WINTER, D. A. et al. **Unified theory regarding A/P and M/L balance in quiet stance**. Journal of Neurophysiology, v. 75, n. 6, p. 2334–2343, jun. 1996.

WONG, S. J. et al. **Smartphone apps for orthopaedic sports medicine – a smart move?** BMC Sports Science, Medicine and Rehabilitation, v. 7, n. 1, dez. 2015.

World Health Organization, Falls, The Problem & Key Facts Sheets Reviewed. Disponível em: <http://www.who.int/mediacentre/factsheets/fs344/en/>.

ZATSIORSKY, V. M.; DUARTE, M. **Instant equilibrium point and its migration in standing tasks: rambling and trembling components of the stabilogram**. Motor Control, v. 3, n. 1, p. 28–38, jan. 1999.

ZATSIORSKY, V. M.; DUARTE, M. **Rambling and trembling in quiet standing**. Motor Control, v. 4, n. 2, p. 185–200, abr. 2000.

2. OBJETIVOS

OBJETIVOS GERAIS

Avaliar a utilização de sensores inerciais de *Smartphones* e outros equipamentos móveis para a avaliação do equilíbrio postural de idosos saudáveis.

Objetivos específicos (Estudo 1)

O Artigo 1 teve como objetivo verificar se os dispositivos móveis e outros gadgets são capazes de avaliar o equilíbrio. Por meio de uma revisão sistemática, foram identificados quais os protocolos utilizados para avaliar o equilíbrio com dispositivos móveis e descrever: (a) os parâmetros utilizados para definir o equilíbrio, (b) as características principais e especificações técnicas de dispositivos e sensores, (c) os modelos matemáticos e algoritmos utilizados para o processamento dos dados.

Além disso, examinamos as potencialidades e limitações dos protocolos para orientar os leitores sobre os mais confiáveis e método conveniente de avaliação de equilíbrio baseado em acelerômetro.

Objetivos específicos (Estudo 2)

O Artigo 2 teve por objetivo determinar a capacidade dos sensores inerciais de um *Smartphone* (iPhone 7) de mensurar a aceleração relacionada às oscilações posturais em tarefas gerais de avaliação de equilíbrio. Foi verificada a concordância entre o telefone celular e um transdutor “padrão ouro” (acelerômetro comercial) e a correlação entre estas medidas de aceleração com parâmetros provenientes de uma plataforma de força, método estabelecido na avaliação do equilíbrio. Buscou-se ainda determinar a capacidade dos sensores inerciais de discriminar diferentes tarefas de equilíbrio e a presença ou ausência de referência visual nas tarefas de postura.

3. Estudo 1

Can we rely on mobile devices and other gadgets to assess the postural balance of healthy individuals? A systematic review

Alexandre S. Pinho [1,2], Ana P. Salazar [1,3], Ewald M. Hennig [4], Barbara C. Spessato [1,3], Antoinette Domingo [5], Aline S. Pagnussat [1,2,3,] *

Artigo submetido à revista *Sensors* - Fator de impacto: 3.031 (2018)

Submetido em: 22 de maio de 2019

Aceito em: 2 de julho de 2019

Publicado em: 5 de julho de 2019

Review

Can we rely on mobile devices and other gadgets to assess the postural balance of healthy individuals? A systematic review

Alexandre S. Pinho [1,2], Ana P. Salazar [1,3], Ewald M. Hennig [4], Barbara C. Spessato [1,3], Antoinette Domingo [5], Aline S. Pagnussat [1,2,3,] *

[1] Movement Analysis and Neurological Rehabilitation Laboratory, Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil; aledopinho@hotmail.com

[2] Health Sciences Graduate Program, Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil; barbaraspessato@gmail.com

[3] Rehabilitation Sciences Graduate Program, Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil; anapsalazar@gmail.com

[4] Queensland University of Technology (QUT), Institute of Health & Biomedical Innovation (IHBI), Kelvin Grove, Brisbane, Australia; e.hennig@qut.edu.au

[5] San Diego State University, School of Exercise and Nutritional Sciences, San Diego, CA, USA; adomingo@sdsu.edu

* Correspondence: alinespagnussat@gmail.com (+55 51 30

Received: 22 May 2019; Accepted: 2 July 2019; Published: 5 July 2019

Abstract: The consequences of falls, costs, and complexity of conventional evaluation protocols have motivated researchers to the development of more effective balance assessments tools. Healthcare practitioners are incorporating the use of mobile phones and other gadgets (smartphones and tablets) to enhance accessibility in balance evaluations with reasonable sensitiveness and good cost-benefit. The prospects are evident as well as the need to question weakness and highlight the strengths of the different approaches. In order to verify if mobile devices and other gadgets are able to assess balance, four electronic databases were searched from their inception to February 2019. Studies reporting the use of inertial sensors on mobile and other gadgets to assess balance on healthy adults, compared to other evaluation methods were included. The quality of the nine studies selected was assessed, and the current protocols often used were summarized. Most studies did not provide enough information about their assessment protocols, limiting the reproducibility and the reliability of the results. The data gathered from the studies did not allow us to conclude if mobile devices and other gadgets have discriminatory power (accuracy) to assess postural balance. Although the approach is promising, the overall quality of the available studies is low to moderate.

Keywords: mHealth; postural balance; wearable electronic devices; mobile applications

1. Introduction

According to the Global Health Organization, falls are the second leading cause of deaths due to accidents or unintentional injury worldwide [1]. The consequences of falls, especially in the older adults population, have drawn attention to the development of fall prevention strategies, focusing on training protocols and more effective/precise balance assessments [1–4].

A wide variety of mathematical models, evaluation protocols, and instruments have been proposed for quantitative measurements of balance. The costs, and complexity of devices for quantitative data make, the assessment and interpretation of results challenging and restricted to academic research or expensive private services [5,6]. Recently, healthcare practitioners have been incorporating the use of less expensive sensors for balance assessment. Mobile phones and other gadgets (smartphones and tablets) have been used because they have triaxial accelerometers and gyroscopes embedded, which turn them into wireless inertial measurement units (IMU). Although these devices have dramatically improved regarding their speed of real-time computing processing and accuracy [7–9], there are still some challenges to overcome. For instance, it is not well understood how this data can be best interpreted and applied to clinical practice [10,11].

Mobile sensors and processing apps (applications/software's) are novel technologies used to enhance accessibility to balance evaluations with reasonable sensitivity and good cost-benefit [12–18]. This technology allows us to assess balance through acceleration measurements resultants calculated using a simplified approach from the position of the center of mass (COM) usually described by an arbitrary (not estimated) single point where the sensor is positioned [19,20]. Some advantages of using inertial sensors from smartphones or tablets to assess balance are: 1- the equipment is affordable and accessible 2- allows real-time evaluations; 3- self-administered protocols; 4- quick and reliable feedback; 5- user-friendly apps and charts reports; 6- easy disseminating results, improving the link between patient, healthcare professionals, and family; 7- ease of understanding and monitoring follow-up [9].

As a disadvantage, we can point out the nature of MEMS sensing technology, which addresses some intrinsic errors to data acquisition, mostly regarding deterministic errors. The main source of these errors is "white noise". These problems may be overcome, in theory, by carefully analyzing data and using specific filters and proper calibration [21]. Smartphone ownership is on the rise in emerging economies, but its cost is still an issue. The global median rate is 59%, but it could be as high as 94% in South Korea, 83% in Israel, 82% in Australia. On the other hand, this rate is reported to be less than 50% in 12 of 22 countries surveyed by the Pew Research Center (2018) or even less in poorer countries.[22]

Even though the use of mobile phones and other gadgets with built-in sensors are not fully validated, the prospects are evident as well as the need to question weakness and strengths of the

different approaches [4,8,9]. The primary outcome of this study was to verify if mobile devices and other gadgets are able to assess balance. The secondary outcomes were, to review the current protocols used to assess balance with consumer-level mobile devices (mobile phones and tablets) and to summarize: (a) parameters used to define balance; (b) the main characteristics and technical specifications of the devices and sensors; (c) mathematical models and algorithms used to process data. Additionally, we examined the potentialities and limitations of protocols to guide readers about the most reliable and convenient method of accelerometer-based balance assessment.

2. Materials and Methods

This systematic review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis - PRISMA and Cochrane guidelines [23,24]. The protocol was recorded at the International Prospective Register of Systematic Reviews – PROSPERO, (CRD42018103481).

2.1. Eligibility and Inclusion Criteria

We included in this systematic review only articles that reported the comparison of general balance evaluation methods to the use of mobile inertial sensors as devices (smartphones and tablets). Regardless of the methods for blinding and randomization, all study designs were included if they assessed standing balance in healthy adults.

2.2. Search Strategy

A systematic search was conducted (from inception to January 2019) using the following databases: PubMed, EMBASE, Scopus and Cochrane Central. The search strategy included terms as 'accelerometry,' 'accelerometer,' 'gyroscope,' 'bodywear sensors,' 'wearable sensors,' 'inertial sensors', 'IMU', 'inertial measurement units', 'mobile application', 'mobile app', 'mobile device', 'smartphone app' and words related to 'Postural Balance,' 'sway,' or 'postural control.' The search was limited to papers written in English, Spanish, and Portuguese with no restriction to date. The complete search strategy is presented in appendix 1. (available as supplementary material online)

2.3. Data Extraction, Risk of Bias and Quality Assessment

Two reviewers (ASP and APS) independently screened the studies by titles and abstracts and deleted duplicates based on the inclusion criteria. After this step, the same reviewers assessed the full texts separately. The authors were contacted by email when data were not available. If the two reviewers did not find a consensus in all phases of the selection (including the screening for the quality assessment), a third reviewer (BCS) made the final decision. All the reviewers were experts at the field with over 10 years of research experience. The EndNoteTM X7 software was used to select and search for articles. The first selection was blinded, and brainstorm was conducted afterward. Three studies were sent to the third senior reviewer who had the final decision. The data extracted from the

included studies were: type of study, number of participants, type and location of the wearable sensor, time acquisition, general conditions of assessments, and primary outcomes of each study.

Methodological quality assessments were performed for all studies using the *Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies* from the United States National Institute of Health (NIH) of the National Heart, Lung and Blood Institute (NHLBI) [25]. A fourteen criteria tool designed for a critical appraisal which involves considering the risk of potential for selection bias. This instrument measures the ability of the study to draw associative conclusions about the effects of the exposures being studied on outcomes. The quality was expressed as a percentage of the total possible score, with a maximum of 2 points for each criterion ("Yes"= 2; "Cannot determine"= 1; "No"= 0). The studies were classified as: "high quality" (>75%), "moderate quality" (>50% to 75%), "low quality" (25% to 50%), and "very low quality" (<25%). Considering the characteristics of papers included in this review, only 12 items were evaluated with a maximum of 24 points (available as supplementary material online - Appendix 2).

Due to the lack of a particular tool to access the consistency of the balance protocols information, we created a *10-point checklist* to access the main information on balance protocols addressing aspects related to measurement bias and reproducibility. Even if this tool did not have its efficacy validated yet, we believe that due to its custom-developed characteristics, it brings light to the presence or not of the main parameters that can possibly influence the results of the balance assessment in general (available as supplementary material online - Appendix 3). For each topic, two researchers gave a yes (Y), or no (N) score and the sum of all topics resulted in the paper's total score (when a topic was "not applicable" a "Y" was given). If the study reached 8 to 10 points, we classified it as being "highly detailed." In other words, a "highly detailed" study presents great consistency, low risk of measurement bias, and enough information to allow reproducibility. If the study was scored between 6 and 7, we classified it as "fairly detailed," or, the study has some risk of measurement bias but is consistent enough to allow reproducibility; finally, a study with less than 6 points, the study was classified as "poorly detailed", or with high risk of measurement bias and/or not fully reproducible (available as supplementary material online - Appendix 3).

3. Results

The initial search identified 1309 studies. After excluding duplicates (427) and screening titles and abstracts, nine papers were considered potentially relevant and were included in this systematic review. All studies included healthy individuals [14,15,17,18,26–30] and had a cross-sectional design and have been published between 2014 and 2019. A flow diagram elucidating the study selection is provided in (Figure 1).

3.1. Sample characteristics

The sample size varied from 12 to 60 individuals. Studies included males and females, from different age groups between 16.4 and 78.9 years. Five studies included only young adults and teenagers. One study categorized subjects into three age groups, young, middle-aged, and older adults [14] and other study selected only the older population [15]. One study did not report the age of the subjects [29], and others didn't present the standard deviation of their sample [27]. Four papers did not report height and body mass of the included subjects [14,15,27,29]. Hsieh et al. selected their sample classifying between high risk and low risk of falls [30]. Table 1 shows the sample characteristics of the studies.

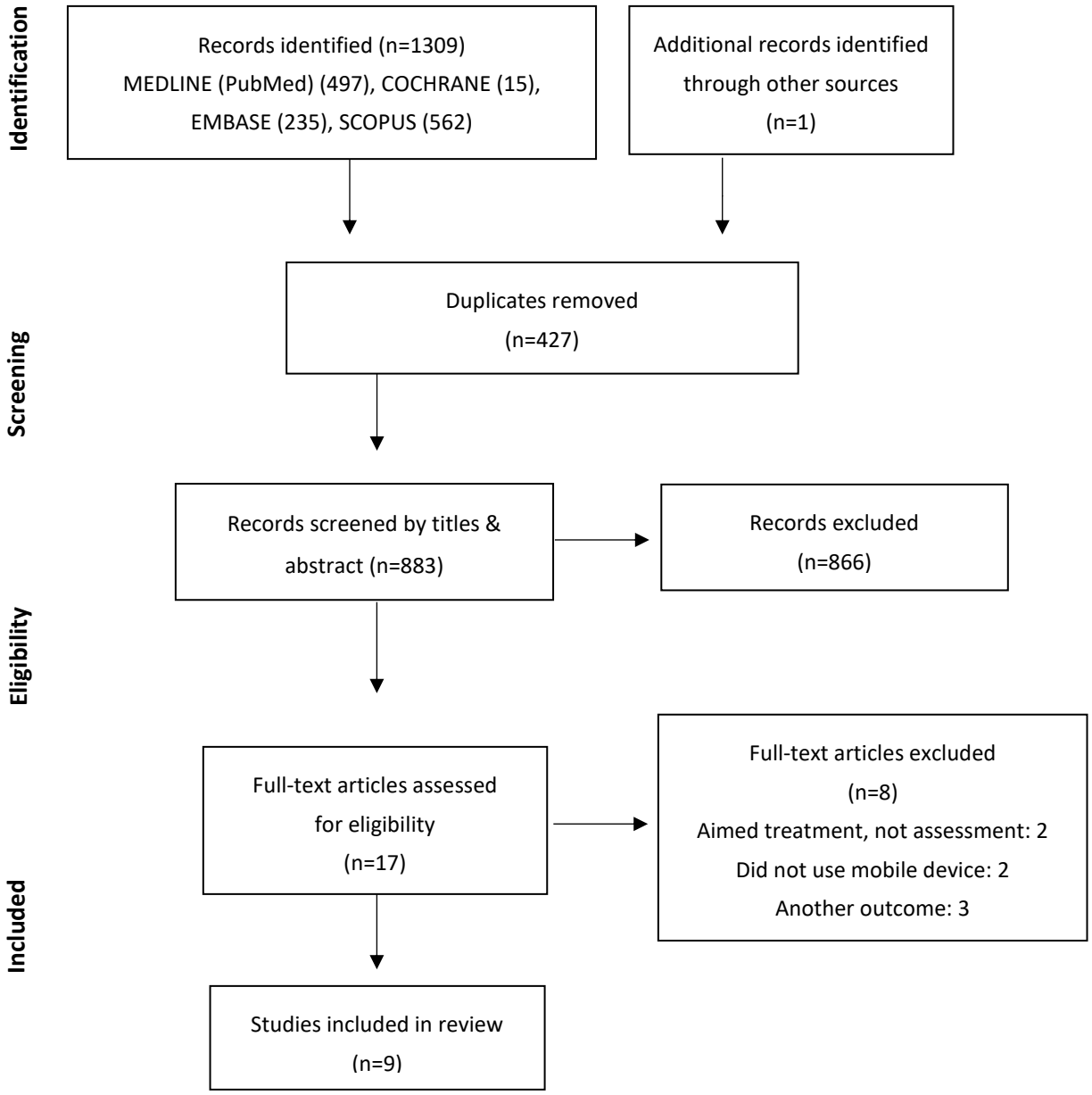


Figure 1 – **Flow diagram**

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

Author	Sample Gender	Age years	Height (cm)[a] Body mass (kg)[b]
Alberts et al, 2015 [23]	n = 49 22 male	19.5 ± 3.1	167.7 ± 13.2 68.5 ± 17.5
Alberts et al, 2015 [24]	n = 32 14 male	20.9 ± NR[c]	NR
Kosse et al, 2015 [14]	n = 60 28 male	26 ± 3.9 (young) 45 ± 6.7 (middle) 65 ± 5.5 (older)	NR
Hsieh et al, 2019 [27]	n = 30 12 male	64.8 ± 4.5 (Low RF) 72.3 ± 6.6 (High RF)	NR
Ozinga et al, 2014 [15]	n = 12 5 male	68.3 ± 6.9	NR
Patterson et al, 2014 [17]	n = 21 7 male	23 ± 3.34	171.66 ± 10.2 82.76 ± 25.69
Patterson et al, 2014 [25]	n = 30 13 male	26.1 ± 8.5	170,1 ± 7,9 72.3 ± 15.5
Shah et al, 2016 [18]	n = 48 21 male	22 ± 2.5	175 ± 9.7 72.57 ± 1.29
Yvon et al, 2015 [26]	n = 50 13 male	NR	NR

[a]cm = centimeter; [b]kg = kilograms; [c]n =sample size; [d]NR = Not reported; [e]RF = Risk of fall

3.2. Overview of studies objectives

All studies had a cross-sectional design and used dedicated *apps* [15,17,18,28,29] or raw data acquisition *apps* to determine the capability to evaluate postural balance [14,26,27]. One study did not report this information [30]. Two studies compared the data acquired using gadgets to "gold standard" balance assessment devices: Biodex Balance System™ [28]] NeuroCom® Smart Balance Master [26]. Other four studies compared gadgets with kinematic data by motion capture system [15,27], commercial accelerometers [14], and force plates [30]. Subjective clinical evaluation tests (full or adapted versions) were performed in five papers [15,17,27–29]. One paper performed the Physiological Profile Assessment (PPA) test on their participants [30]. The PPA test measures fall risk based on vision, reaction time, leg strength, proprioception, and balance which gives a score and characterizes individuals between low risk and high risk of fall [31]. The iOS (Apple Inc.) was the operating system of seven studies [14,15,17,26–29], and the Android (Google Inc.) were at two studies [18,30].

3.3. Balance assessment protocols

Tasks used to evaluate postural balance varied across the studies and included: *Balance Error Scoring System* (BESS)[15,17,27]], *Athlete Single Leg Test* [28] , *Romberg and tandem Romberg tests* [29], NeuroCom® *Sensory Organization Test* (SOT) [27] , *SWAY Balance Test* [17,28] , and other general tasks [14,18,30] , (Table 2).

Table 2. Tasks and balance assessment protocol.

Author	Assessed tasks	Feet condition	Feet position	Hands/arms position	Visual input	Visual reference
Alberts et al, 2015 [23]	Six conditions NeuroCom® SOT[a]	According to SOT	According to SOT	According to SOT	EO/EC[b]	According to SOT
Alberts et al, 2015 [24]	Six conditions BESS[c]	Wearing socks	According to BESS	Resting on the iliac crests	EC	NA[d]
Kosse et al, 2015 [14]	Two conditions 1- Quiet standing 2- a Dual-task (letter fluency test)	NR[e]	Parallel Semi-tandem	NR	EO/EC	NR
Hsieh et al, 2019 [27]	1- Quiet standing 2- a Dual-task (subtracting numbers)	Wearing socks	(NC[f]) Semi-tandem Tandem Single leg	dominate hand holding phone medially against the chest	EO/EC	NR
Ozinga et al, 2014 [15]	Six conditions adapted from BESS	Barefoot	According to BESS	Resting on the iliac crests	EO/EC	3m target
Patterson et al, 2014 [17]	Six conditions BESS (adapted) Five conditions S*way Test*	Shoed	According to BESS	Holding Mobile at Sternum mid-point	EC	NA
Patterson et al, 2014 [25]	Single condition Athlete's Single-Leg Test	NR	Non-dominant foot stance	Holding Mobile at Sternum mid-point	EO	NR
Shah et al, 2016 [18]	Eight conditions	Barefoot	Apart Together Tandem	On the hips	EO/EC	4.37m target
Yvon et al, 2015 [26]	Romberg and tandem Romberg tests in Sixteen conditions	NR	Apart Together Tandem	Sidearms	EO/EC	NR

aSOT= Sensory Organization Test; bEO= Eyes open; EC= Closed eyes; cBESS= Balance error scoring system. dNA= Not applicable; eNR= Not reported; fNC= Not clearly stated.

One paper used the six formal conditions of BESS [27], which is performed with eyes closed for 20s: (1) double-leg stance, firm surface; (2) single-leg stance, firm surface; (3) tandem stance, firm surface (dominant leg in front of the other); (4) double-leg stance, foam surface; (5) double-leg stance, foam surface; and (6) tandem stance, foam surface. Patterson, Amick, Pandya, *et al.* 2014 [17] adapted the BESS by modifying the hand's position during the test. Lastly, one study altered the BESS conditions adjusting the test to an older population [15]. The author modified the analysis by excluding the single-leg stance, performing some parts of the test with open eyes.

One study followed the NeuroCom® protocol device [26], which uses the NeuroCom® Sensory Organization Test (SOT) resulting in an equilibrium score. The protocol includes several procedures that combine stable and unstable surface with open and closed eyes, as well as with an oscillation of the visual references. The authors evaluated 49 individuals through Neurocom to determine whether an accelerometer and gyroscope data sampled from a consumer electronics device (iPad2) could provide enough resolution of the center of gravity (COG) movements to accurately quantify postural stability. Six conditions of SOT were used to compare the scores generated and calculated from both

devices. Limits of agreement were defined as the mean bias (NeuroCom - iPad) +2 standard deviations. Through the comparison of the real-time center of gravity sway, they found that the best agreement by the mean difference in equilibrium scores was of 0.01% for the SOT-1 and the largest difference was -6.2% for the SOT-5.

Two other papers performed the SWAY Balance Test [17,28]. This test consists of five stances including single-leg stance, feet together and tandem during 10s on a firm surface with eyes closed. One article evaluated 30 young individuals performing a single trial of the Athlete Single Leg Test requesting the subjects to stand on their non-dominant foot for 10s [28]. Balance scores were generated from arbitrary units of both systems determined by undisclosed calculations. The balance scores derived from the smartphone accelerometers (SWAY Balance Mobile Application software) were consistent with balance scores obtained from the Biodex System, showing no significant differences ($p = 0.818$) between the means. A significant correlation between the two data sets was found ($p < 0.01$, $r = 0.632$).

Other tasks chosen by authors included a dual-task protocol with a "letter fluency test" in a parallel stance and a semi-tandem stance with eyes open and closed [14] and with a concurrent cognitive challenge, having the participants simultaneously subtracting by seven from a random number between 100 and 200 [30]. Eight different conditions were used with the myAnkle application and are detailed in tables 1 and 2 [18]. One paper used the *Romberg test and the Romberg tandem test* performed with and without noise restriction. Subjects went through a combination of sixteen postures, including open and closed eyes, feet together, and tandem, on a firm and foam surface [29].

3.3.1. Feet and arms position

Regarding the feet position, some papers followed closed protocols [15,17,26,27]. Other studies evaluated only a non-dominant single-leg stance, feet parallel, and semi-tandem], tandem, feet closed together and apart [18]], or yet feet together and tandem [29]. Studies used a barefoot condition [15,18,27] or assessed subjects wearing socks [26] or shoes not specifying the type [17]. Four studies did not describe the feet condition [14,28,29], and one study described partially [30].

Regarding the arms or hands position, three articles used a software application protocol where subjects held the mobile at the sternum mid-point [17,28,30]. Three papers described the position of the "hands" instead of "arms", which were resting on the subjects iliac crests [15,27] or on the subject's hips [18]. Authors also instructed subjects to "rest the arms at body side" according to the device's protocol of SOT [26]] and to use the same "arms position of Romberg's tests" [29]. One paper did not specify this information [14].

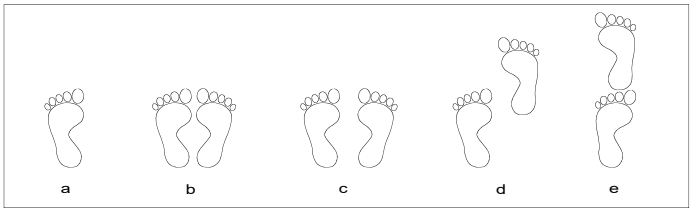


Figure 2. Feet positions: a = Single-leg, b = Feet together, c = Feet apart, d = Semi-tandem, e = Tandem

3.3.2. Visual reference

Two studies described a visual target reference during the mobile data acquisition which was located at 3m [15] and 4m [18] ahead but didn't mention the height from the ground and size of the target. Four authors did not report visual reference. In other studies, this aspect could not be analyzed due to a closed eyes condition [17,27] or some specific visual task [26].

3.3.3. Number of acquisitions, sessions and total time of acquisition

Most studies conducted only one trial of data acquisition [14,17,18,27–29] while others performed three [26] and two trials [15,30]. The time acquisition ranged between 10 and 60s. None of the articles used or reported using a time window (cropped time) at the analysis (Table 3). Three studies used a well-established sampling rate recommendation of 100Hz [10] for balance data acquisition [15,26,27]. In three other studies, the rates varied from 200Hz [30], 88-92 Hz [14] to 14-15 Hz [18]. Three articles did not fully describe the sampling rates [17,28,29] (Table 3).

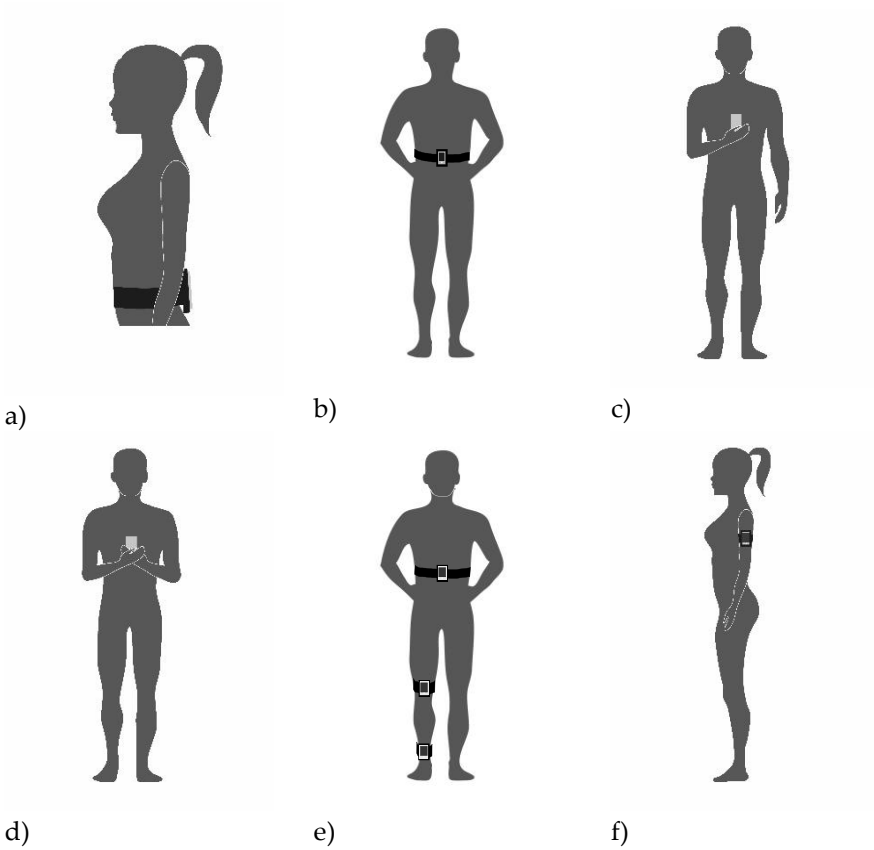


Figure 3. Devices and arms positions: a= Lumbar or sacral region arms not reported [14,26]; b= Lumbar or sacral region [15, 27]; c= Sternum dominated hand [30]; d = Sternum both hands [17, 28] e = Malleolus, patella, umbilicus [18] f = left upper arm [29].

Table 3. Balance protocol procedures, devices and technical specifications.

Author	Number of trials	Total time (Time cropped) seconds	Device I Device II (Sampling rate)	Device position	App used for acquisition	Synchronization
Alberts et al, 2015 [23]	3	20s (NR[a])	iPad2 (100Hz) NeuroCom® (100Hz)	Sacrum	Sensor Data by Wavefront Labs	LabVIEW data collection program.
Alberts et al, 2015 [24]	1	20s (NR)	iPad (SNR[b]) (100Hz) Eagle 3D Motion analysis System (100Hz)	Sacrum	Cleveland Clinic Concussion	Arduino Pro Mini 3.3v and a LED light
Kosse et al, 2015 [14]	1	60s (NR)	iPod Touch (88-92Hz) Accelerometer DynaPort® hybrid unit (100Hz)	L3 vertebrae	iMoveDetection	Cross-correlation analysis
Hsieh et al, 2019 [27]	2	30s (NR)	Samsung Galaxy S6 (200Hz) Force plate (Bertec Inc, Columbus, OH) (1000Hz)	Sternum	NR	NR
Ozinga et al, 2014 [15]	2	60s (NR)	iPad 3 (100Hz) Eagle 3D Motion analysis System (100Hz)	Second sacral vertebrae	Cleveland Clinic Balance Assessment	Arduino Pro Mini 3.3v and a LED light
Patterson et al, 2014 [17]	1	10s *STS*[c] 20s BESS (NA[d])	iPod Touch (NR) NA	Sternum midpoint	SWAY Balance Mobile	NA
Patterson et al, 2014 [25]	1	10s (NR)	iPod Touch (NR) Biodex© Balance System (NR)	Sternum midpoint	SWAY Balance Mobile	NR
Shah et al, 2016 [18]	1	(NR)	LG Optimus One (14-15Hz) NA	Malleolus Patella Umbilicus	myAnkle	NR
Yvon et al, 2015 [26]	1	30s (NR)	iPhone (SNR) NA	Participant's left upper arm	D+R Balance	NR

[a]NR = Not reported; [b]SNR = Specification of the device not reported; [c]STS = Sway Test Software; [d]NA= Not applicable.

Only one study presented test-retest reliability. The author repeated data acquisition twice. Although the description indicates that the test-retest was within the same day with a short interval, there was no time interval reported between acquisitions [14]. The intraclass correlation coefficient (ICC) values found for the Root Mean Square (RMS) of the accelerations was 0.83 and 0.90 and for the Sway Area was 0.81 and 0.91 during parallel stance and semi-tandem stance respectively.

3.3.4. Measurement device and position

Studies used different wearable sensors (Table 2). Three studies used iPad devices [15,26,27], three used iPods [14,17,28] and three used smartphones, an iPhone [29], a LG Optimus One [18] and a Samsung Galaxy S6 [30]. Four studies reported placing the mobile sensor on the participants' lumbar or sacral region [14,15,26,27]. Three studies placed the gadget on the sternal midpoint [17,28,30], one on the left upper arm [29] and another one positioned three devices on different body places (malleolus, patella, umbilicus) [18].

3.3.5. Devices synchronization

Acquisitions of data with the use of more than one equipment in which the time phases must occur at the same time, theoretically presuppose the use of a synchronization method. Three studies did not report any synchronization method [18,28,30], while four studies adequately described this process [14,15,26,27]. In two articles the synchronization procedure did not apply [17,29].

3.6.6. Measurements and Signal processing parameters

The primary signal processing parameters used in quantitative continuous data measurements are briefly listed (available as supplementary material online - Appendix 4) as stated in the study. Some studies reported using the raw data to run their own post-processing algorithms for the computing balance metrics [14,15,26,27,30]. One author designed a mobile phone app [18]. Other authors did not report if they had access to the APP algorithm or calculations [17,28,29].

3.7. Methodological Quality Assessment

3.7.1. Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies NIH-NHLBI

Three papers were classified as having "low quality" (from 25% to 50%) [17,28,29] and five papers as "moderate quality" (from > 50% to 75%) [14,15,18,26,27,30]. Neither articles were considered as very "low quality" (<25%) nor as "high quality" (>75%), (available as supplementary material online - Appendix 2).

3.7.2. A 10-point checklist for balance assessment protocols

Four studies were classified as "highly detailed" [15,18,26,27]. One study was considered "fairly detailed" [17], and four studies were considered "poorly detailed" [14,28–30] (available as supplementary material online - Appendix 3).

4. Discussion

This study aimed to review systematically the current protocols used to assess balance with mobile devices. We provided an overview of parameters used to define balance, main characteristics of devices and technical specifications, mathematical models, and algorithms used to process data. Briefly, we found that studies presented good consistency about the assessment procedures. Yet, we found a widespread lack of standardization in data acquisition, which compromises the data repeatability and reproducibility. Besides, methods to evaluate the mobile capability in assessing balance were too varied among studies, as well as the mathematical models, variables, tasks, and posture conditions.

It is well known that methodological aspects like anthropometric characteristics, time of acquisition, feet, and arms position can influence the results and the reliability of measurements of postural balance. So, these parameters must be controlled and described in detail in scientific papers as it has been already established in the literature [10,20,32,33]. Five articles did not report height and body mass data [14,15,27,29,30]. Normalization methods for a proper comparison among subjects were reported by a few studies [15,27]. Height and body mass is an essential anthropometric characteristic affecting the base of support and the COM position, thus, these parameters must be controlled or normalized while comparing groups or describing samples to assess balance. For individual assessments by clinicians or customers, this issue could be of less importance, considering these parameters are less susceptible to changes.

Another aspect to be considered in balance evaluation protocols is the time of acquisition. Time of acquisition ranged from 10 to 60s in the included papers. The literature describes that time of acquisition may result in slight changes in balance parameters [32]. However, the shorter the time acquisition, the higher the synchronization control of devices must be, which was not a point of concern for all authors. We highlight the time of acquisition as another aspect that influence decisions about mathematical models and data processing methods [32].

Feet and arms positions are directly related to the physics concepts of stability. Moving the feet apart increases the size of the base of support and the capacity of stabilizing, as evidenced by patterns of the center of pressure (COP) variables [34]. On the other hand, the position of arms can alter the body oscillations and stability by slight changes in the COM affecting the base of support. This is another critical point to be considered. The studies included in this review used a wide range of feet and arms positions and most studies used different restricted postures during the balance assessment. The body oscillation is changed when an individual is restricted or not to a specific posture. So, the data acquired from different protocols may be diverse not allowing comparison, or not reflecting the general characteristics of balance in some cases.

Based on the physics concepts, the best way to describe balance and its displacement remain an open question [35–39]. It is very common to use the COM sway represented estimated as a single point around the base of the lumbar spine [37]. Another possibility is to use the COP trajectories, which represents a weighted average of all the pressures over the surface at the base of support

[35,36,38,39]. These two parameters are measured by different techniques and the position of the sensors can influence the results. The majority of studies positioned the sensors on the pelvis, lumbar and sacral vertebra [14,15,26,27]. Some studies have chosen the upper limbs [29], lower limbs [18] and chest [17,28,30] to place the sensors. The trunk seems to be the best option due to the proximity of the body COM avoiding also unwanted movements of limbs interfering with balance assessment. A previous study showed good to excellent test-retest reliability using acceleration rates and COP parameters when the sensor is placed in the lumbar region [12], reinforcing this statement.

We cannot define if the best choice is to fix the device in some specific area of the body or just ask for the individual to hold the device on their own. Encouraging the individual to hold the device would favor the self-administration of balance tests and empower patients to care about their health but could compromise data acquisition. Positioning near or away from the body's center of mass will influence the movement degree of freedom caused by specific joints strategies for balance control [12]. The choice of the device position would affect the relative plane orientation and influence the repeatability and data accuracy. Although there is a lack of studies covering those aspects, it is known is that the design of applications and decisions on protocol procedures induce specific and carefully data processing. Also, the algorithm must be in conformity with the theoretical approach [8].

One of the major's concerns in protocols of balance evaluation is the time acquisition. In studies included in this review, time acquisition ranged from 10 to 60 seconds. The shorter the time interval chosen, the more caution measures had to be taken due to the accuracy needed for synchronizing the devices. Also, the time of acquisition critically influence the decisions on the mathematical model and data processing methods [32]. Selecting a time window (cropped time window) is a usual procedure in quantitative balance analysis when a few seconds are withdrawn from the total acquisition time (arbitrarily) at the beginning and at the end of each attempt. Although not clear in the literature, it has been justified by reducing disturbing movements in the initial posture and attenuating the effects of fatigue, ensuring steadiness with less unwanted "noise" and "artifacts" in the signal. None of the papers reported using this method. The main objective of the studies selected was a comparison between sensors and devices, what probably dispense the use of this procedure, but raises a doubt whether it would increase or not the sensitivity of the protocols and data correlation.

A test-retest approach might have enhanced also the results, which was performed only by one study [14]. Likewise, the number of acquisitions, although a previous study which compared the acceleration data to the center of pressure reported that the data from three trials are similar to those obtained in only one trial [12]. Even being a signal with stochastics characteristics, it is suggested that only one trial may be reliable and useful to be applied in clinical practice.

Signal processing methods were varied among studies and included the calculation of COM, COP, and raw acceleration through the measurements of RMS, the standard deviation, the maximum peak of displacement, maximum amplitude displacement, and sway area. All of these parameters

can be applied in balance assessments [40]. One study used the raw acceleration data as a parameter to define stability, which is not a direct measurement of the position and is an unusual method to describe stability. A previous systematic review explored the best outcomes to assess standing balance and walking stability in subjects with Parkinson's disease. The authors included 26 studies and defined "jerk" (the time derivative of acceleration) and trunk RMS acceleration as the most useful measures to differentiate patients from healthy controls [41].

It is important to highlight the use of two "gold standard" clinical devices to evaluate young individuals. One aimed a validation of measurement with a specific mobile software [28] concluding that the scores from the smartphone were consistent with the validated balance system. The other compare equilibrium scores [26] calculating the limits of agreement between the devices. The author concludes that mobile hardware provided data of sufficient precision and accuracy to quantify postural stability is a reasonable approach for in clinical and field environments. At the *Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies NIH-NHLBI,* the studies ware ranked as "low quality" [28] and "moderate quality" [26], respectively. At the *10-point checklist for balance assessment protocols*, they achieved "poorly detailed" [28] and "highly detailed" [26], respectively.

This systematic review presents some limitations that make challenging to state recommendations about the most appropriate protocol to assess balance using gadgets. The majority of studies included in this review did not provide sufficient information about their assessment protocols, which make difficult the reproducibility of the evaluation, the reliability of the results and limiting the judgment of the discriminatory power (accuracy) of studies to assess postural balance. The overall quality of studies included in this review was low to moderate using the methodological *Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies* from the NHLBI - NIH weakening the consistency of the conclusions from the studies due to the lack of information on the internal and external validity and possible increase of risk of bias. It is important to state also; that the *10-point checklist for balance assessment protocols* used to assess the studies in this review is a custom-developed tool and is not validated for its efficacy, although was created based upon authors expertise and after a detailed discussion of the methods presented.

Considering the quality of the evaluation procedures, technical specifications and data processing information, only four studies were classified as "highly detailed" [15,18,26,27], restricting the reproducibility of the protocols. Finally, most studies lack a direct sensor comparison, using a "gold standard" transducer system to determine the accuracy of the various transducer outputs from mobile devices, a question that still has to be addressed.

5. Conclusions

The results from this systematic review did not allow to perform an evaluation of the diagnostic and accuracy tests as expected. Thus, from our preliminary findings, we cannot ensure the use of mobile devices and other gadgets to assess postural balance. However, two studies presented consistent data supporting enough accuracy and good reliability for the use of this method to evaluate healthy young individuals. Due to the differences in hardware and operating systems, the comparisons between several mobile phone systems that are currently on the market is still a fragile aspect that needs to be ensured. Clear balance protocol information, anthropometric characteristics of the sample, and technical specifications of the equipment and sensors are indispensable and have to be stated. Further studies are highly encouraged, with adequate sample size, different population, test-retest measurements and low risk of bias are necessary to provide a better understanding of this promising approach.

Supplementary Materials:

Author Contributions:

Alexandre S.P. and A.P.S. conceived, analyzed the data and wrote the manuscript with support from B.C.S. at the experiment design. E.M.H. analyzed the data and review the manuscript with A.D. A.S. Pagnussat, review the manuscript and supervised the project along with E.M.H. All authors discussed the results and contributed to the final manuscript.

Funding: This study was partially financed by the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES - Brasília, DF, Brazil)* – Finance Code 001.

Acknowledgments: The authors would like to thank the research funding agency Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES - Brasília, DF, Brazil) for the scholarship granted [88881.135564/2016-01] Alexandre S.P.; for the Ph.D. scholarship granted to Ana P.S. and Alexandre S.P.; for the Post-Doc scholarship of B.C.S.

Conflicts of Interest: The authors have no conflicts of interest to declare.

Appendix 1 - Search strategy (Databases)

Appendix 2 - Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies – NIH – NHLBI

Appendix 3 – 10-point checklist for balance assessment protocols

Appendix 3 – 10-point checklist for balance assessment protocols

Apêndice 1

Appendix 1 - Search strategy (Databases)

MEDLINE accessed by Pubmed, Embase, Cochrane, SCOPUS up to February 2019.

The search of the (Pubmed, Embase, and SCOPUS) databases was using the terms as follows:

#1

"Accelerometry"[Mesh]

"Accelerometer"

"Gyroscope"

"Bodywear sensors"

"Wearable sensors"

"Wear sensor"

"Inertial sensors"

"IMU"

"inertial measurement unit"

#2

"App Mobile"[Mesh]

"Apps, Mobile"

"Application, Mobile"

"Applications, Mobile"

"Mobile Application"

"Mobile Apps"

"Portable Electronic Apps"

"App, Portable Electronic"

"Apps, Portable Electronic"

"Electronic App, Portable"

"Electronic Apps, Portable"

"Portable Electronic App"

"Portable Electronic Applications"

"Application, Portable Electronic"

"Applications, Portable Electronic"

"Electronic Application, Portable"

"Electronic Applications, Portable"

"Portable Electronic Application"

"Portable Software Apps"

"App, Portable Software"

"Apps, Portable Software"

"Portable Software App"

"Software App, Portable"

"Software Apps, Portable"

"Portable Software Applications"

"Application, Portable Software"

"Applications, Portable Software"

"Portable Software Application"

"Software Application, Portable"

"Software Applications, Portable"

"mobile device"

"mobile smartphone"

"smartphone application"

"smartphone app"

#3

"Postural Balance"[MESH]

"Balance, Postural"

"Musculoskeletal Equilibrium"

"Equilibrium, Musculoskeletal"

"Postural Equilibrium"

"Equilibrium, Postural"

"Musculoskeletal Equilibrium"

"Equilibrium, Musculoskeletal"

"Postural Equilibrium"

"Equilibrium, Postural"

"Balance, Postural"

"sway"

"postural control"

"body sway"

#1 AND #2 AND #3

Database: Chocrane (up to February 2019)

"Accelerometer"OR"Mobile applications"AND"Postural Balance"

Apêndice 2

Appendix 2 - Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies – NIH – NHLBI

	Quality Assessment															
Study	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**	**%**
Alberts et al, 2015 [23]	2	2	2	2	0	0	0	2	2	2	2	-	-	0	16	67%
Alberts et al, 2015 [24]	2	2	2	2	2	0	0	2	0	0	2	-	-	2	16	67%
Kosse et al, 2015 [14]	2	2	2	2	2	0	0	2	0	2	2	-	-	0	16	67%
Hsieh et al, 2019 [27]	2	2	2	2	2	0	0	2	2	0	2	-	-	0	16	67%
Ozinga et al, 2014 [15]	2	2	2	2	2	0	0	2	2	0	2	-	-	2	18	75%
Patterson et al, 2014 [17]	2	2	2	2	2	0	0	2	0	0	1	-	-	0	13	50%
Patterson et al, 2014 [25]	2	2	2	2	2	0	0	0	0	0	2	-	-	0	12	50%
Shah et al, 2016 [18]	2	2	2	1	2	0	0	2	2	0	2	-	-	2	17	71%
Yvon et al, 2015 [26]	2	1	2	2	0	0	0	2	0	0	1	-	-	0	10	42%

The quality was expressed as a percentage of the total possible score, where each criterion could reach a maximum of 2 points ("Yes"= 2; Not Clear= "1"; "No"= 0). The studies were classified as: "high quality" (>75%), "moderate quality" (>50% to 75%), "low quality" (25% to 50%), and "very low quality" (<25%). Items 12 and 13 were considered not applicable due to the designs characteristics of studies.

Appendix 3 – 10-point checklist for balance assessment protocols

Author	Sample information	Tasks description	Feet condition	Feet and arms position	Visual reference eyes	Visual reference target	Cropped time	Sampling rates	Data/signal processing method	Synch method	Total score
Alberts et al, 2015 [23]	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	9
Alberts et al, 2015 [24]	N	Y	Y	Y	Y	Y_(NA)	N	Y	Y	Y	8
Kosse et al, 2015 [14]	N	Y	N	N	Y	N	N	Y	Y	Y	5
Hsieh et al, 2019 [27]	N	Y	Y	N	Y	N	N	Y	Y	N	5
Ozinga et al, 2014 [15]	N	Y	Y	Y	Y	Y	N	Y	Y	Y	8
Patterson et al, 2014 [17]	Y	Y	Y	Y	Y	Y_(NA)	N	N	Y	Y_(NA)	8
Patterson et al, 2014 [25]	Y	Y	N	Y	Y	N	N	N	Y	N	5
Shah et al, 2016 [18]	Y	Y	Y	Y	Y	Y	N	Y	Y	N	8
Yvon et al, 2015 [26]	N	Y	N	Y	Y	N	N	N	N	Y_(NA)	4

Cropped time = Total time acquired *minus* Time window analyzed; *Synch* = Synchronization; Y = yes; N= no; Y_(NA) = for a "not applicable" item a "Y" was given.

Apêndice 4

Appendix 4 – Overview (Description of parameters and measurements as stated in the study and general comments)

Author	Overview	Parameters and measurements	General Comments on the Strengths and Limitations
Alberts et al, 2015 [23]	Used the **Neurocom® device** through force plate measurements with **Sensory Organization Test** (SOT) to determine whether an iPad2 provides sufficient resolution of the center of gravity (COG) movements to quantify postural stability in healthy young people accurately.	Center of pressure (COP) of the anterior-posterior (AP) and medium-lateral (ML) sway; Three-dimensional (3D) device-rotation rates and linear acceleration; COG of the AP angle was used for all outcomes.	Only sample curves are shown for the CoG-AP sways for conditions 1, 4, 5 and 6. No numerical data are given for the actual physical measures from the Neurocom A-P sway-data as compared to the calculated A-P sway-data from iPad sensor. Nevertheless, the overall performance of the iPad for predicting the Equilibrium Score of the Neurocom appears excellent. The 100 Hz data sampling is more than sufficient to determine low-frequency body sways, probably using the smaller gadget/mobile, rather than the large iPad-2 may have resulted in even better results.
Alberts et al, 2015 [24]	Assessed the accuracy of the iPad by comparing the metrics of postural stability with a **3D motion capture system** and proposed a method of quantification of the Balance error scoring system (BESS) using the center of mass (COM) acceleration data.	3D Position, linear and angular accelerations of the COM at the AP and ML; 3D Linear acceleration and rotation-rate; (1) peak-to-peak (2) normalized path length (3) Root mean square (RMS) of the displacements COM (4) 95% ellipsoid volume of sway; A spectral analysis of ML, AP, and trunk (TR) acceleration.	No numerical data were compared between the motion capture results and the calculated values from the iPad sensors. Only correlations were calculated, and no raw data were presented, what leave readers not sure of the measurements consistency. This applies to table 1, where no raw data for normalized path length (NPL), peak-to-peak (P2P), and RMS are presented, just comparisons with low to medium rho values. The small (Correlation coefficient) Rho values of only 0.55 and less (table 2) for the iBESS Volume against the error score is even less convincing - but this can also be due to the low reliability of the subjective error scoring. The iPad sensors are probably much better able to detect balance deficits as compared to the more subjective BESS.
Kosse et al, 2015 [14]	Compared to the data from a stand-alone **accelerometer** unit to establish the validity and reliability of gait and posture assessment of an iPod.	AP and ML trunk acceleration and a resultant vector (1) RMS accelerations of body sway in AP and ML (2) sway area; (3) total power median of the signal from frequency spectrum signals.	Good direct comparison study from an iPod with a "Gold Standard" DynaPort triaxial accelerometer. For comparing wave, similarity Cross-correlations were determined after time normalization (100 Hz). The values were around 0.9 for all experimental conditions in AP and ML directions suggesting a high-quality acceleration signal and software evaluation. Time-lag values were almost identical between the two transducers. Validity and test-retest reliability intraclass-correlations (ICC) values were also excellent for RMS signals in both the AP and ML direction. Only for the median power frequency (MPF) lower ICC´s were found for the test-retest reliability, (possibly caused by the different sampling frequencies, requiring time normalization procedures. Excellent and comprehensive analysis, including a measurement section for a pure comparison of transducer technology as well as application to groups of 3 age group participants.

Hsieh et al, 2019 [27]	Static balance tests were conducted while standing on a force plate and holding a smartphone. COP data from the force plate and acceleration data from the smartphone were compared. Validity between the measures was assessed and the Correlations coefficients were extracted to determine if a smartphone embedded accelerometer can measure static postural stability and distinguish older adults at high levels of fall risk.	The COP parameters included in the analysis were: (1) 95% confidence ellipse and (2) velocity in the anteroposterior (AP) direction and mediolateral (ML) direction. From the smartphone, (1) maximum acceleration in the ML, vertical, and AP directions and (4) root mean square (RMS) in the ML, vertical, and AP axis were exported and processed.	A promising approach was used to distinguish subjects with risks of falling associating acceleration data and COP parameters to the "physiological profile assessment" which is an evaluation of the risk of falling based on the assessment of multiple domains. Strong significant correlations between measures were found during challenging balance conditions (ϱ = 0.42-0.81; p <0.01-0.05). Correlations that, to some extent, were expected although it seems to be quite difficult to differentiate between vertical, AP, and ML components between the force plate and the accelerometer. Especially, during challenging balance tasks, there will be quite a bit of movement of the upper extremities against the body, creating all kinds of extra accelerations at the phone. A more trustful comparison of acceleration data from the phone to the force plate seems only possible if the phone would have been fastened at the CoG of subjects or close to the CoG.
Ozinga et al, 2014 [15]	Simultaneous kinematic measurements from a **3D motion analysis** system during balance conditions were used to compare the movements of COM to investigate if an iPad can provide sufficient accuracy and quality for the quantification of postural stability in older adults.	Angular velocities and linear accelerations were processed to allow direct comparison to Position of whole-body COM; (1) peak-to-peak displacement amplitude (2) normalized path length (3) RMS displacements of COM (4) 95% ellipsoid volume of sway. Spectral analysis of the magnitude of the ML, AP, and trunk acceleration was used.	Fairly high correlations were present between the cinematographic, and the iPad derived data, suggesting that the iPad would be a good alternative to cinematographic posture analyses. Procedures and methods were well chosen. However, the number of subjects was fairly low.
Patterson et al, 2014 [17]	Compared the scores of a mobile technology application within an iPod through balance tasks with a commonly used subjective balance assessment, the **BESS**.	Balance scores by 3D Acceleration measurements;	An inverse relationship of r= -0.77 (p <0.01) was found between the BEES score and the SWAY results. Thus, the iPod acceleration signals were proven to be a fairly good predictor of stability. An elevated BESS score reflected a high number of balance errors, whereas the SWAY Balance score assigns a higher value to more stable performance. The fact that subjects had to press the iPod with their hands against the sternum brings some weakness to the tests procedures. It restricts freedom for balancing their body in the five exercises and introducing mechanical artifacts by having their hands at the sensors during balancing task. Because no direct comparisons between two sensors were made, only an indirect estimation of the quality of the iPod touch transducer can be made. Most likely, the major error of the limited r= -0.77 is not a function of the quality of the iPod sensor but rather a consequence of poor BESS rating quality. Mentioning yet, that BESS scoring test was done by only two people. However, since BESS is well accepted, this paper shows, that mobile phone integrated sensors are well suited for evaluating postural stability.

Patterson et al, 2014 [25]	A Biodex© Balance System which gives an AP Stability Index from a **force platform** was used to compare and evaluate the validity of a Balance Mobile Application which uses the 3D accelerometers from an iPod while subjects were performing a single trial of the Athlete Single Leg Test protocol.	Degree of tilt about each axis: (1) ML stability index, (2) AP stability index and the (3) overall stability index; The displacement in degrees from level was termed the "balance score" from the AP stability index (APSI).	AP stability index (APSI) score on the balance platform 1.41 was similar to the smartphone SWAY score 1.38 with no statistically significant difference. However, the correlation (ICC) between the scores was low - only r= 0.632 ($p<0.01$). As it was the case in the Patterson et al., 2014a, the same weakness was found, once the subjects had to hold the iPod touch with both hands at the sternum and only sway in AP direction was measured. Other than indicated the authors, an ICC of only r= 0.632 appears very low when considering that the same measure was taken by two systems at the same time for a single leg stance.
Shah et al, 2016 [18]	A mobile application was developed to provide a method of objectively measuring standing balance using the **phone's accelerometer**. Eight independent therapists ranked a balance protocol based on their clinical experience to assess the degree of exercise difficulty. The concordance between the results was obtained to determine if the mobile can quantify standing balance and distinguish between exercises of varying difficulty.	3D accelerometer data were obtained from three mobile phones and mean acceleration was calculated; After a correction for static bias the corrected value was applied, the magnitude of the resultant vector (R) was calculated for each of measurement; The metric "mean R" was the average magnitude all resultant vectors and was then used as an index of balance.	Even though Shah et al., 2016 did not make a direct comparison between 2 sensor systems, accelerometer readings were calculated for each exercise at each ankle and knee and the torso. A high differentiation between the stability exercises shows lower values for ankle, knee, and torso, indicating that the acceleration results from the mobile phones have a strong relationship to the subjective rating of the 8 experienced clinicians. The results indicate that one sensor location appears sufficient since all sensors follow the same trend, it appears that knee and torso locations could be used. From a practical point of view, easiest to mount and use would be the torso or hip location.
Yvon et al, 2015 [26]	An iPhone application was used to quantify sway while performing the Romberg and the Romberg tandem tests in a soundproof room and then in a normal room.	Output data ('K' value) was used to represent the area of an ellipse with two standard deviations in the anterior-posterior and lateral planes about a mean point.	The article explores a not usual protocol trying to evaluate the contributions of auditory sensory inputs on balance, through a combination of postures in different sound room condition. No raw data were presented or clearly specified; data processing procedures were not reported. Differences in postural sway measurements have been found among different room conditions with a dedicated application.

References

1. World Health Organization, Falls, The Problem & Key Facts Sheets Reviewed [Internet]. 2018. Available from: http://www.who.int/mediacentre/factsheets/fs344/en/ , [accessed 2018 Apr 7] [http://www.webcitation.org/734VSaCIc]

2. Lee, J.; Geller, A.I.; Strasser, D.C. Analytical Review: Focus on Fall Screening Assessments. PM&R. 2013 Jul;5(7):609–21. https://doi.org/10.1016/j.pmrj.2013.04.001]

3. van der Kooij, H.; van Asseldonk, E.; van der Helm, F.C.T. Comparison of different methods to identify and quantify balance control. J Neurosci Methods. 2005 Jun;145(1–2):175–203. https://doi.org/10.1016/j.jneumeth.2005.01.003]

4. Fabre, J.M.; Ellis, R.; Kosma, M.; Wood, R.H. Falls risk factors and a compendium of falls risk screening instruments. J Geriatr Phys Ther. 2010;33(4):184–197. [Medline: 21717922]

5. Baratto, L.; Morasso, P.G.; Re, C.; Spada, G. A new look at the posturographic analysis in the clinical context: sway-density versus other parameterization techniques. Motor Control. 2002 Jul;6(3):246–70. [doi: 10.1123/mcj.6.3.246 ·]

6. Clark, S.; Riley, M.A. Multisensory information for postural control: sway-referencing gain shapes center of pressure variability and temporal dynamics. Exp Brain Res. 2007 Jan;176(2):299–310. [doi: 10.1007/s00221-006-0620-6]

7. Wong, S.J.; Robertson, G.A.; Connor, K.L.; Brady, R.R.; Wood, A.M. Smartphone apps for orthopedic sports medicine – a smart move? BMC Sports Sci Med Rehabil [Internet]. 2015 Dec [cited 2017 Jul 7];7(1). Available from: http://bmcsportsscimedrehabil.biomedcentral.com/articles/10.1186/s13102-015-0017-6

8. del Rosario, M.; Redmond, S.; Lovell, N. Tracking the Evolution of Smartphone Sensing for Monitoring Human Movement. Sensors. 2015 Jul 31;15(8):18901–33. [doi: 10.3390/s150818901]

9. Dobkin, B.H.; Dorsch, A. The Promise of mHealth: Daily Activity Monitoring and Outcome Assessments by Wearable Sensors. Neurorehabil Neural Repair. 2011;25(9):788–98. [doi: 10.1177/1545968311425908]

10. Ruhe, A.; Fejer, R.; Walker, B. The test-retest reliability of center of pressure measures in bipedal static task conditions – A systematic review of the literature. Gait Posture. 2010 Oct;32(4):436–45. [https://doi.org/10.1016/j.gaitpost.2010.09.012]

11. Habib, M.; Mohktar, M.; Kamaruzzaman, S.; Lim, K.; Pin, T.; Ibrahim, F. Smartphone-Based Solutions for Fall Detection and Prevention: Challenges and Open Issues. Sensors. 2014 Apr 22;14(4):7181–208. [doi.org/10.3390/s140407181]

12. Whitney, S.L.; Roche, J.L.; Marchetti, G.F.; Lin, C-C.; Steed, D.P.; Furman, G.R.; et al. A comparison of accelerometry and center of pressure measures during computerized dynamic posturography: A measure of balance. Gait Posture. 2011 Apr;33(4):594–9. [doi: 10.1016/j.gaitpost.2011.01.015]

13. Chung, C.C.; Soangra, R.; Lockhart, T.E. Recurrence Quantitative Analysis of Postural Sway using Force Plate and Smartphone. Proc Hum Factors Ergon Soc Annu Meet. 2014 Sep;58(1):1271–5. [doi: 10.1177/1541931214581265]

14. Kosse, N.M.; Caljouw, S.; Vervoort, D.; Vuillerme, N.; Lamoth, C.J.C. Validity and Reliability of Gait and Postural Control Analysis Using the Tri-axial Accelerometer of the iPod Touch. Ann Biomed Eng. 2015 Aug;43(8):1935–46. [doi: 10.1007/s10439-014-1232-0]

15. Ozinga, S.J.; Alberts, J.L. Quantification of postural stability in older adults using mobile technology. Exp Brain Res. 2014 Dec;232(12):3861–72. [doi:10.1007/s00221-014-4069-8]

16. Ozinga, S.J. Quantification of postural stability in Parkinson's disease patients using mobile technology [Internet]. Cleveland State University; 2015 [cited 2017 Jul 7]. Available from: http://rave.ohiolink.edu/etdc/view?acc_num=csu1450261576 ; [doi: 10.1007/s00221-014-4069-8]

17. Patterson, J.A.; Amick, R.Z.; Pandya, P.D.; Hakansson, N.; Jorgensen, M.J. Comparison of a Mobile Technology Application with the Balance Error Scoring System. Wilkerson G, editor. Int J Athl Ther Train. 2014 May;19(3):4–7. [doi: 10.1123/ijatt.2013-0094]

18. Shah, N.; Aleong, R.; So, I. Novel Use of a Smartphone to Measure Standing Balance. JMIR Rehabil Assist Technol. 2016 Mar 29;3(1):e4. [doi: 10.2196/rehab.4511]

19. Mayagoitia, R.E; Lötters, J.C.; Veltink, P.H.; Hermens, H. Standing balance evaluation using a triaxial accelerometer. Gait Posture. 2002 Aug;16(1):55–9. [doi: 10.1016/S0966-6362(01)00199-0 ·]

20. Neville, C.; Ludlow, C.; Rieger, B. Measuring postural stability with an inertial sensor: validity and sensitivity. Med Devices Evid Res. 2015 Nov;447. [doi: 10.2147/MDER.S91719]

21. Tang, P.V.; Tan, T.D.; Trinh, C.D. Characterizing Stochastic Errors of MEMS-Based Inertial Sensors, 32 (2016) 9.

22. Poushter, J.; Caldwell, B.; Hanyu, C. Social Media Use Continues to Rise in Developing Countries but Plateaus Across Developed Ones, [s.d.], 46. (2018) Available from: https://assets.pewresearch.org/wp-content/uploads/sites/2/2018/06/15135408/Pew-Research-Center_Global-Tech-Social-Media-Use_2018.06.19.pdf

23. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097. [doi: 10.1371/journal.pmed.1000097]

24. Chandler, J.; Higgins, J.P.; Deeks, J.J.; Davenport, C.; Clarke, M.J. Cochrane Handbook for Systematic Reviews of Interventions, 50. Available from: https://community.cochrane.org/book_pdf/764

25. National Heart, Lung, and Blood Institute (NHLBI) of the United States National Institute of Health (NIH). Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies. Available from: https://www.nhlbi.nih.gov/health-pro/guidelines/in-develop/cardiovascular-risk-reduction/tools/cohort ; [Webcitation.org/734XGu7N9]

26. Alberts, J.L.; Hirsch, J.R.; Koop, M.M.; Schindler, D.D.; Kana, D.E.; Linder, S.M.; et al. Using Accelerometer and Gyroscopic Measures to Quantify Postural Stability. J Athl Train. 2015 Jun 2;50(6):578–88. [doi: 10.4085/1062-6050-50.2.01]

27. Alberts, J.L.; Thota, A.; Hirsch, J.; Ozinga, S.; Dey, T.; Schindler, D.D.; et al. Quantification of the Balance Error Scoring System with Mobile Technology: Med Sci Sports Exerc. 2015 Oct;47(10):2233–40. [doi: 10.1249/MSS.0000000000000656]

28. Patterson, J.A.; Amick, R.Z.; Thummar, T.; Rogers, M.E. Validation of measures from the smartphone sway balance application: a pilot study. Int J Sports Phys Ther. 2014 Apr;9(2):135–9. [Medline: 24790774]

29. Yvon, C.; Najuko-Mafemera, A.; Kanegaonkar, R. The D+R Balance application: a novel method of assessing postural sway. J Laryngol Otol. 2015 Aug;129(08):773–8. [doi: 10.1017/S0022215115000912]

30. Hsieh, K.L.; Roach, K.L.; Wajda, D.A.; Sosnoff, J.J. Smartphone technology can measure postural stability and discriminate fall risk in older adults. Gait Posture. 2019 Jan;67:160–5. [doi : 10.1016/j.gaitpost.2018.10.005]

31. Lord, S.R.; Menz, H.B.; Tiedemann, A. A Physiological Profile Approach to Falls Risk Assessment and Prevention. Phys Ther. 2003 Mar 1;83(3):237–52. [doi: 10.1093/ptj/83.3.237]

32. Scoppa, F.; Capra, R.; Gallamini, M.; Shiffer, R. Clinical stabilometry standardization. Gait Posture. 2013 Feb;37(2):290–2. [doi: 10.1016/j.gaitpost.2012.07.009]

33. Evans, O.M.; Goldie, P.A. Force platform measures for evaluating postural control: reliability and validity. 1989 Aug; Archives of Physical Medicine and Rehabilitation(70(7):510-7). [Medline: 2742465]

34. Kirby, R.L.; Price, N.A.; MacLeod, D.A. The influence of foot position on standing balance. J Biomech. 1987;20(4):423–427. [doi: 10.1016/0021-9290(87)90049-2]

35. Winter, D.A. Human balance and posture control during standing and walking. Gait Posture. 1995;3(4):193–214. [doi: 10.1016/0966-6362(96)82849-9]

36. Zatsiorsky, V.M.; Duarte, M. Instant equilibrium point and its migration in standing tasks: rambling and trembling components of the stabilogram. Motor Control. 1999 Jan;3(1):28–38. [Medline: 9924099]

37. Morasso, P.G.; Spada, G.; Capra, R. Computing the COM from the COP in postural sway movements. Hum Mov Sci. 1999 Dec 1;18(6):759–67. [doi: 10.1016/S0167-9457(99)00039-1]

38. Zatsiorsky, V.M.; Duarte, M. Rambling and trembling in quiet standing. Motor Control. 2000 Apr;4(2):185–200. [doi: 10.1123/mcj.4.2.185]

39. Lin, D.; Seol, H.; Nussbaum, M.A.; Madigan, M.L. Reliability of COP-based postural sway measures and age-related differences. Gait Posture. 2008 Aug;28(2):337–42. [doi: 10.1016/j.gaitpost.2008.01.005]

40. Deshmukh, P.M.; Russell, C.M.; Lucarino, L.E.; Robinovitch, S.N. Enhancing clinical measures of postural stability with wearable sensors. Conf Proc Annu Int Conf IEEE Eng Med Biol Soc IEEE Eng Med Biol Soc Annu Conf. 2012;2012:4521–4. [doi: 10.1109/EMBC.2012.6346972]

41. Roeing, K.L.; Hsieh, K.L.; Sosnoff, J.J. A systematic review of balance and fall risk assessments with mobile phone technology. Arch Gerontol Geriatr. 2017 Nov;73:222–6. [doi: 10.1016/j.archger.2017.08.002]

4. Estudo 2

Smartphones: a reliable acceleration-based measurement device for assessing basic balance tasks of healthy individuals

Alexandre S. Pinho, Tiago Becker, Ewald M. Hennig, Milton Antonio Zaro, Aline S. Pagnussat

Artigo a ser submetido à revista *Sensors* - Fator de impacto: 3.031 (2018)

Smartphone's: a reliable acceleration-based measurement device for assessing basic balance tasks of healthy older adults

Alexandre S. Pinho[1,2], Tiago Becker[4,5], Ewald M. Hennig[6], Milton Antonio Zaro[4,7], Aline S. Pagnussat[1,2,3,*]

[1] Movement Analysis and Neurological Rehabilitation Laboratory, Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil; aledopinho@hotmail.com

[2] Health Sciences Graduate Program, Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil;

[3] Rehabilitation Sciences Graduate Program, Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA), Porto Alegre, RS, Brazil;

[4] Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil;

[5] Mechanical Engineering Department- Mechatronics and Control Laboratory (LAMECC); tiago.becker@ufrgs.br

[6] Queensland University of Technology (QUT), Institute of Health & Biomedical Innovation (IHBI), Kelvin Grove, Brisbane, Australia; e.hennig@qut.edu.au

[7] Graduate Program in Informatics & Education, Porto Alegre, Rio Grande do Sul, Brazil; zaro@ufrgs.br

* Correspondence: alinespagnussat@gmail.com; Tel.: +55-5133038912

Received: date; Accepted: date; Published: date

Abstract: 200

Protocols for balance assessment based on smartphone technology are novel alternatives in a clinical environment and have been explored, although its reliability is not fully addressed. The ability of the built-in Smartphone inertial sensors to measure acceleration signals during balance tasks was tested against two gold-standard devices. A sample of 33 healthy older adults (26 females) over 60 years (69.3 ± 4.8) underwent a fall risk questionnaire, clinical balance tests, and quantitative tests. A commercial transducer provided "true values" of acceleration data, and the center of pressure (COP) parameters associated with postural balance captured by a Force Plate was compared to the Smartphone (iPhone 7) acceleration signals. The anteroposterior (AP) and mediolateral (ML) *Root mean Square* (RMS) data were analyzed. The Pearson's correlations between data from both devices' (Smartphone x Accelerometer) measurements were very strong and the agreement between measures tested by the intra-class correlation coefficient (ICC) with a 95% confidence interval showed a positive interaction of 0.996 for the RMS AP (CI 95% = 0.995 – 0.997) and 0.969 for RMS ML (CI 95% = 0.960 – 0.976). When acceleration data were compared to COP measurements (Smartphone x Accelerometer x Force Plate), fair to moderate correlations were found Smartphone demonstrated fair to moderate correlations for most balance parameters analyzed, and its sensors provide enough information for balance acceleration-based measurements.

Keywords: mHealth; postural balance; wearable electronic devices; mobile applications

1. Introduction

As life expectancy growths and all-natural aging-related impairments emerge, it raises the risk of a fall event, which is associated with high levels of morbidity and mortality among older adults [1–3]. The attempts to create protocols based on wearable sensors for postural assessment in clinical use is increasing. Smartphone applications are promising alternatives due to the low cost, use easiness, reasonable sensitivity of their inertial sensors, and the widespread adherence to this technology by consumers [4–6].

Protocols for quasi-static equilibrium have been explored in literature in several ways, tasks, and different equipment [5,7–13]. However, the reliability of smartphone acceleration signals is not entirely addressed, even though these devices have the potential to surpass traditional methods for clinical purposes [14]. It has been reported that mobile devices can measure postural balance, determine stability or mobility level [15–17], infer on stroke patients balance [18] assist at the management of concussion and mild traumatic brain injury [19,20] distinguish healthy from Parkinson's diseases individuals [21] and discriminate fall risk in older adults [22]. Even though the number of studies in this subject has increased, the methodological quality of some works is low to moderate. Still, there are a few issues that need to be improved to support evidence-based information for routine use and treatment decisions [7].

The micro-electro-mechanical systems embedded on smartphones can detect slight movements and allow the estimation of the body's position and its oscillations. The assessment of postural balance, however, involves mathematical procedures and models often affected by inherent hardware biases. Anti-aliasing filters, resampling, and interpolation methods are specific signal processing methods technics can overcome these issues [23].

Other drawbacks need to be highlighted. The consistency of the algorithms depends on proper sensor placement, also considering that approaches related to the inverted pendulum model are proven to be more consistent with sensors positioned as close as possible to the body's center of mass [4,24]. The compensatory movements for maintaining stability are different among individuals and also for distinct balance dysfunctions. In a controlled evaluation environment, the displacements are affected by disturbances related to the postural strategies and the specificity of each task. Therefore, some balance parameters will be more sensitive than others to identify patterns on specific populations [4]. The variety of mobiles on the market, hardware specifications, and architecture singularities of the systems are critical and add uncertainties to the technic reliability. The reduced information available on the methodological

protocols of some studies reduces reproducibility giving place to uncertainties, and the lack of a direct sensor comparison is a prime concern frequently not addressed in studies [8].

Understanding the metrics and decoding the oscillation data into clinical information is essential for describing the postural motor function and the limits of stability. This information gathered contributes to promising balance risk management tools and the development, for instance, of more effective fall detection applications [25]. Therefore, the main objective of this work was to determine the agreement between measurements of the inertial sensors of a Smartphone to acquire acceleration data of healthy older adults performing balance tasks. The outputs were compared to a gold standard transducer, the discrepancies were determined, and the results were correlated against a well-established method of balance assessment.

2. Materials and Methods

Subjects and experimental design

This cross-sectional study was conducted at the Movement Analysis and Rehabilitation Laboratory of the Federal University of Health and Sciences of Porto Alegre from October 2018 to February 2019. Healthy older adults were recruited by convenience according to the following inclusion criteria: Age over 60 years, independent walking, able to perform all the balance tasks with or without a history of a falling event. Individuals were excluded if they had orthopedic or neurological problems that could interfere with the evaluations and if they were under medication that might affect their postural control. The Ethical Committee of the Federal University of Health Sciences of Porto Alegre approved this research (CAAE: 88790418.2.0000.5345). All participants signed the written informed consent.

Data collection

All data were collected on the same day, by the same evaluator and in the following order:

1) Anamnesis and demographic information.

2) Montreal Cognitive Assessment (MOCA) - a brief cognitive screening for older individuals [26]

3) *Falls Efficacy Scale* (FES) - rates from 0 to 10 the confidence in doing ten activities in or outside the home without falling [27].

4) *Unipedal Stance Test* (UPST) - is performed with eyes open and eyes closed. This is a quick and simple test associated with increased risk of falling depending on the time measured, mainly by closed eyes condition. It is widely used and has been associated with frailty profile and level of self-independence in activities of daily living [28].

5) *Timed Up and Go Test* (TUG) - a time-test that assesses mobility and requires both static and dynamic balance. The individual starts in a seated position, and stands up upon voice command, walks 3 meters, turns around a plastic cone, walks back to the chair and sits down. The results of TUG were at the preliminary session for general functional health characterization [29].
6) The Force Plate, Accelerometer, and Smartphone protocol – as described below.

Balance assessment procedures

Data were acquired using a force plate (SMART DX 400 - BTS Bioengineering), a capacitive triaxial accelerometer (Slam Stick™, Mide Technology, Woburn, USA), and an iPhone 7 (Apple Inc. Cupertino, California, USA). Participants stood at a force plate wearing a belt which was firmly attached at the waist, centered positioned at the lumbar area, with the Smartphone and the accelerometer fixed together. The height of the devices related to the ground was measured (Figure 1). The instruction was to stand still in a comfortable way with both arms at the side, with feet close together while maintaining their gaze at a target 3m away at eye level.

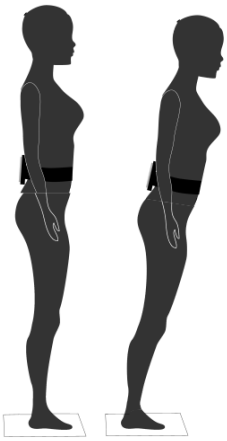


Figure 1- Participants position, wearing a belt with the Accelerometer and Smartphone attached at the lumbar area while standing still (a) and leaning forward (b) on a force plate.

Data were acquired in three sets of evaluations in three different balance tasks: 1) standing still with eyes open; 2) standing still with eyes closed; 3) leaning forward with eyes open – LOS (functional stability limit test) (Figure 1). The time of acquisition was of 60s captured for each subject in a randomized order for each opened and eyes closed task. The leaning-forward tasks were performed at the end of each session with a one-minute interval, and the best trial was chosen for analysis (highest AP amplitude). All valid tests were used for the correlation analysis between the acceleration-based devices through the raw data and the processed data (RMS values of the acceleration). For balance correlations, the mean value of RMS acceleration from each task of the Smartphone was compared to the center of pressure (COP) postural balance parameters. A 30 seconds time-window was extracted for data analysis (from the 60s time

acquisition - we discarded the first and last 15 seconds to prevent unwanted motion artifacts due to adaptation or fatigue) [30,31].

To verify the ability of the Smartphone to measure acceleration during different strategies and extreme amplitudes of postural sway, after the quiet standing tasks, an adapted functional stability limit test was proposed based on the protocol Grzegorz Juras et. Al [32]. The functional stability limit test (LOS) is a range of the COP excursion during a leaning forward task traditionally measured by force plates and describes the motor control strategies for postural sway. The perceived limit of stability defines the distance bounds that can be adopted in a standing position while moving forward without losing the balance or taking a step [33]. We instructed the participants to lean forward at their own pace and reach their maximal range without losing the balance control and not raising the heels from the force plate. A maximal leaning position should be maintained until the end of the trial [33,34].

Instrumentation

Three independent devices captured data in each referred task. A single tridimensional force platform BTS SMART DX 400 (BTS Bioengineering) acquired the data for the center of pressure (COP) calculated from the ground reaction forces and moments. A threshold of 10N was set to sense the vertical peak and establish the beginning of the acquisition by the individual bumping the ground. A low-pass fourth-order Butterworth digital filter of 10 Hz was applied, and the Sway software (1.4.10.7 BTS Bioengineering) calculated the COP displacements for the anteroposterior (AP) and mediolateral (ML) directions. The parameters analyzed were a) Mean displacement = the mean value calculated from the displacement of a given direction during the time interval; b) Standard deviation displacement = the standard deviation calculated from the displacement of a given direction during the time interval; b) Total range = The difference between the maximum and the minimum range displacement; c) Maximum radius = Is the maximum COP distance from the barycenter of the individual; d) Inertial axis = Represents the magnitude vector of the axes of the inertial ellipse regarding the x-axis of the reference system Regression angle: e) Total area = Represents the size of an ellipse area that encloses 95% of the observations of the COP trajectory. We chose these parameters based on the coherence of acceleration-related data to the COP measurements [5,8,10,13,35].

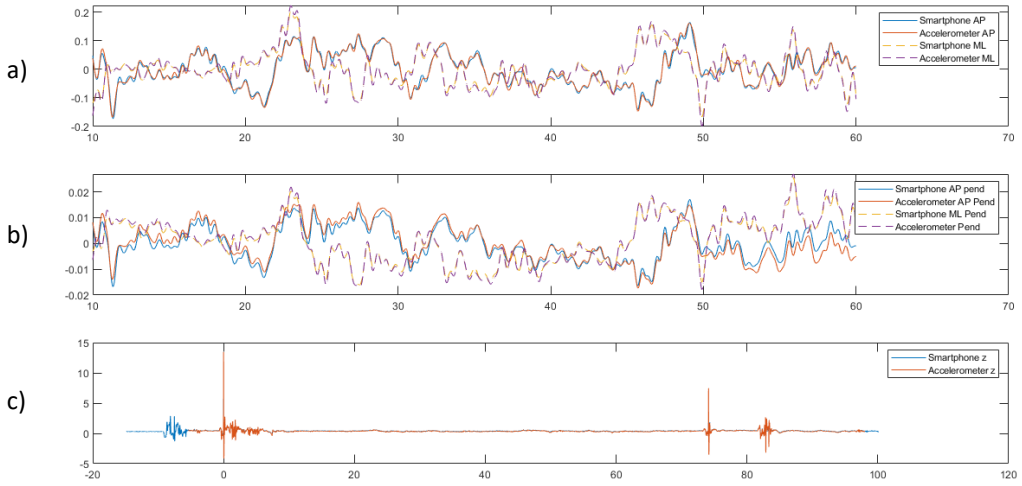
A capacitive triaxial accelerometer was used to assess the anteroposterior (AP) and mediolateral (ML) trunk acceleration (Slam Stick™, Mide Technology, Woburn, USA) DC response micro-electro-mechanical systems (±16g or 200g) 3,200 Hz | 13 bit with dimensions of 7.6 x 2,3 x 1,5cm, and with an 8Gb Data Logger. Additionally, an iPhone 7 (Apple Inc. Cupertino,

California, USA) was fixed to the accelerometer to acquire data by a double face tape in a way that a touch pen could assess the mobile screen during the procedures. The application ***Sensor kinetics Pro*** (2.1.2 copyright 2009, INNOVATIONS, INC.) loaded in the mobile phone recorded the raw acceleration data which were exported for analysis. A time delay of 10s was set by a trigger system in all devices to guarantee the subjects to maintain an upright steady position before starting the acquisition.

Signals processing procedures

The sampling rate used in the sensors was set to 100 Hz per channel. However, the app used on the smartphone was not able to maintain an accurate sampling. Thus, for post-processing, it was necessary to resample the signal for the chosen rate. In the preprocessing phase, the signals were filtered with a 10 Hz cutoff frequency and then were synchronized from the initial peak acceleration from the vertical component present on all signals as a result of an intentional motion inserted into the procedure for this purpose.

The force and raw acceleration data from the devices were processed using the software MATLAB 2019a (MathWorks®, Inc, Massachusetts, USA). Each data set passed through visual inspection of the curves to determine the quality of the signal and the time-window of the beginning of the acquisition from the vertical axes (Figure 2). Before extracting the AP and ML acceleration data, the average tilt from gravitational components was subtracted, resulting in a horizontal-vertical orthogonal coordinate system. This procedure corrected static accelerations due to the misalignment of the Accelerometer axes and average inclination of the spine [11].



Smartphone = Smartphone raw acceleration data; Accelerometer = Accelerometer raw acceleration data; AP = anteroposterior; ML = Mediolateral; Pend= Inverted pendulum; Smartphone z = Smartphone vertical component of acceleration; Accelerometer z = Accelerometer vertical component of acceleration.

Figure 2 – Acceleration curves from both devices (graphs a and b) and individuals peaks (tap) on force plate for synchronization (graph c);

To compare the Smartphone data to the force plate balance parameters, acceleration signals were processed according to two different approaches commonly used to estimate the position in space and assess postural balance [11]. The first approach isolates the dynamic component of accelerations on each axis and, from a process of double integration of accelerations, and calculates the displacement. One limitation of this approach is that the displacements are of low amplitude (range of movement) and low frequency, resulting in very low accelerations. The magnitude of the oscillations, therefore, adds numerical errors into the estimation of the position. This process, although found in some balance works is suggested to have biases also due to the "measurement noise" and drift, which increases with integration in time, even in the absence of any motion of the accelerometer [36].

The second approach considers the individual's trunk movement, like an inverted pendulum [37], which is another method widely used to evaluate postural balance [38]. The inverted pendulum is considered a simplification of the humans standing posture characterized by ankle joint motion stability strategies [12,14,39]. In this case, accelerations measured on each axis were regarded as components of the acceleration of gravity, and the variations were due to the change in accelerometer inclination. Thus, the inclination angle of the accelerometer concerning the vertical axis was estimated, which, together with the height of the sensor to the center of rotation of the inverted pendulum, allowed an estimate of the accelerometer displacement [12,37,39]. The resultant sum of the absolute values from each axis, meaning the "magnitude of the displacement" at the double integration method and the inverted pendulum oscillation method was calculated and denominated *Total Displacement* [11,14,40,41].

Finally, the acceleration *Root Mean Square* of the two axes (RMS_{AP} and RMS_{ML}) were calculated for the gold standard accelerometer correlation. The RMS is the average energy of a signal over a time interval, represents its variance, and is used as a measure of stability or postural steadiness [42,43]. Higher accelerations RMS magnitude is associated with higher postural oscillations and adjustments found in more challenging stability tasks and balance disorders [11,14,44].

Statistics

Data normality and homogeneity were assessed by Kolmogorov-Smirnov and Levene's tests, respectively. The adequacy of the sample size used for the analysis was determined based upon the estimate's methods proposed by Zou 2011 [45]. The number of observations to ensure that the lower limit of a 95% one-sided confidence limit for 80% assurance for two variables was

estimated to a minimum of 61 observations. For postural parameters comparison, the calculated sample was of 18 participants [46]. Pearson's correlation was used to evaluate the relationship between results from both acceleration-based devices. Correlations were considered Perfect (1.00), Very Strong (0.8 to 0.99), Moderate (0.6 to 0.79), Fair (0.3 to 0.59), Poor (0.1 to 0.29), and None (0) [47,48]. The agreement between the measurements was assessed by an Intra-class correlation test (ICC). The differences between the RMS App from the RMS Acc, for each trial, within the all measures was evaluated with a *Students t-test*. Bland-Altmann plots were used to identify systematic differences (bias) between the acceleration devices. The mean results from the displacement calculated by the double integration and the inverted pendulum method were compared to the force plate balance parameters.

3. Results

The sample of 33 healthy adults aged between 60 and 83 years, showed a normal distribution and consisted mostly of physically active subjects (30/33 = 90%) with a low frequency of falling events; one event in the last six months (4/33 = 12%). There was no significant difference among individuals related to all variables. The demographic information of all participants is presented in Table 1.

Table 1. Demographic information

Sample	Age (years)	Mass (kg)	Height (m)	BMI (m/cm2)	TUG Max (s)	FES	UPST EO max (s)	UPST EC max (s)
n=33	69.3	71.37	1.64	26.59	6.99	20	14.435	2.46
26 females	(± 4.8)	(± 11.84)	(± 0.1)	(± 3.86)	(± 1.35)	(22.5 - 30.5)	(42.5 - 45)	(3.98 - 5.29)

Descriptive statistics of the data described by mean and standard deviation ± SD, and median and confidence intervals inner bound and upper bound (shaded); BMI = Body mass index; TUG = Timed up and go test; max= Maximum; FES = Falls Efficacy Scale; UPST EO= Unipedal Stance Test with eyes open; UPST EC= Unipedal Stance Test with eyes closed.

Table 2 depicts data acquired through Force Plate, Accelerometer, and Smartphone in both tasks: eyes open and eyes closed. Table 3 shows the RMS data obtained using the Accelerometer and the smartphone. Paired t-tests evidenced no differences from RMS data acquired by the Accelerometer and the Smartphone.

Table 2. Results of acceleration and force plate balance parameters from 33 individuals standing with eyes open and eyes closed.

Data	Device	Parameter	Eyes condition	
			Eyes open	Eyes closed
Center of pressure data (COP)	Force plate	Mean displacement AP (mm)	-25.92 (-33.41 , -18.42)	-33.68 (-41.08 , -26.28)
		SD displacement AP (mm)	5.39 (4.79 , 6.00)	5.64 (4.83 , 6.45)
		Mean displacement ML (mm)	-2.15 (-11.28 , 6.97)	14.87 (2.88 , 26.87)
		SD displacement ML (mm)	4.72 (4.16 , 5.27)	5.65 (4.80 , 6.50)
		Maximum radius (mm)	17.78 (15.86 , 19.68)	19.92 (17.33 , 22.51)
		Total range AP (mm)	25.99 (22.71 , 29.27)	28.64 (25.31 , 31.98)
		Total range ML (mm)	25.02 (22.11 , 27.93)	28.95 (24.48 , 33.42)
		Trace length (mm)	709.07 (651.82 , 766.32)	856.98 (772.01 , 941.95)
		Mean velocity (mm/s)	23.64 (21.73 , 25.55)	28.57 (25.74 , 31.40)
		SD velocity (mm/s)	13.99 (12.63 , 15.35)	17.10 (15.21 , 18.98)
		Inertial axis AP (mm)	5.99 (5.21 , 6.78)	5.99 (5.29 , 6.69)
		Inertial axis ML (mm)	4.35 (3.80 , 4.89)	5.09 (4.37 , 5.82)
		Regression angle (Degrees)	0.37 (-4.21 , 4.96)	1.64 (-3.36 , 6.66)
		Total area (mm2)	92.02 (71.95 , 112.09)	110.95 (83.78 , 138.11)
Acceleration data	Accelerometer	RMS AP (m/s^2)	0.070 (0.059 , 0.074)	0.075 (0.065 , 0.086)
		RMS ML (m/s^2)	0.048 (0.04 , 0.055)	0.057 (0.044 , 0.069)
		Total displacement Pendulum (cm)	30.84 (26.86 , 34.82)	70.00 (38.39 , 101.60)
		Total displacement Integration (cm)	44.52 (37.86 , 51.18)	39.4436 (33.24 , 45.64)
	Smartphone	RMS AP (m/s^2)	0.068 (0.058 , 0.073)	0.075 (0.064 , 0.086)
		RMS ML (m/s^2)	0.047 (0.041 , 0.053)	0.054 (0.044 , 0.064)
		Total displacement Pendulum (cm)	29.71 (26.143 , 33.29)	57.37 (37.09 , 77.64)
		Total displacement Integration (cm)	15.5227 (13.24 , 17.79)	19.09 (16.03 , 22.15)

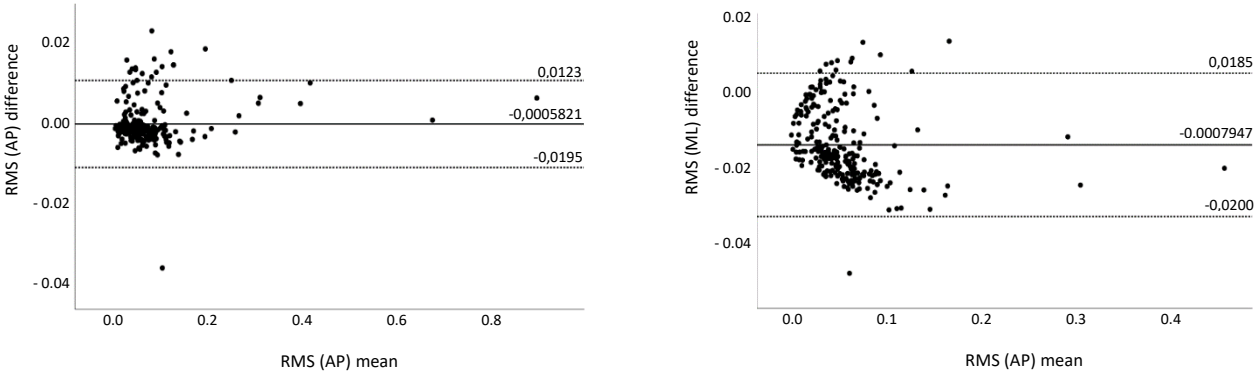
Data expressed by median and confidence intervals.

Table 3. Acceleration results from Accelerometer and the Smartphone from all data sets (n= 33 individuals).

Parameter	Mean	Std. Deviation	95% Confidence Interval		p-value
			Lower	Upper	
RMS_{AP} Smartphone	0.070	0.034	0.064	0.078	0.163
RMS_{AP} Accelerometer	0.071	0.033	0.065	0.078	
RMS_{ML} Smartphone	0.050	0.029	0.045	0.057	0.174
RMS_{ML} Accelerometer	0.052	0.036	0.045	0.060	

Descriptive statistics of the device's data described by mean, standard deviation ± SD and 95% Confidence Interval.
RMS= Root mean square; AP = Anteroposterior; ML= Mediolateral

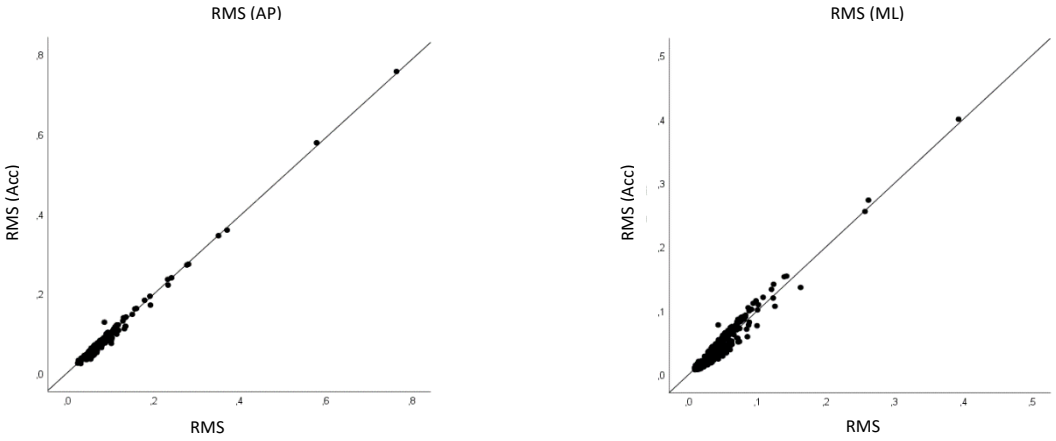
The Bland-Altmann analysis was performed to depict differences between the RMS measurements plotted against the mean measures from both acceleration devices (Figure 3). The good level of agreement found is indicated by the proximity of the dataset within the lines, which bounds the limits of agreement, although the RMS_{ML} graph is presented sparser than RMS_{AP}. The mean percentage difference between measures was -1,42% for the AP and of -3,92% for the ML. Negative values represent the magnitude mean value underestimated by the Smartphone compared to the gold standard acceleration device.



RMS= Root mean square; Smartph= Smartphone; Acc= Accelerometer; AP= Anteroposterior; ML= Mediolateral

Figure 3 - Bland-Altmann plots showing the limits of agreement (upper and lower lines within IC 95%) between the mean measurements (central line) from both devices for all individuals' valid trials with eyes open and eyes closed at AP and ML axes.

Pearson's correlations between the acceleration data from both devices' (smartphone x Accelerometer) for AP and ML measures were considered very strong (Table 4; Figure 4). When acceleration data were compared to COP measurements (force plate), fair to moderate correlations were found [47,48]. Pearson's correlations from both acceleration devices (smartphone x Accelerometer) for AP and ML measures are presented in Table 4.



Smartph= Smartphone; Acc= Accelerometer; AP= Anteroposterior; ML= Mediolateral

Figure 4 - Pearson's correlations between the acceleration data from both devices (smartphone x Accelerometer) for AP and ML measures (n= 252)

Table 4 - Pearson's correlations (r-value) between the acceleration data from both devices' measurements (Smartphone x Accelerometer) for AP, ML, *Total Displacement* (by Double Integration and Inverted Pendulum methods) compared to force plate balance parameters.

	Accelerometer Data		Force Plate Balance Data						
	RMS Acc (AP)	**RMS Acc (ML)**	SD Displacement (AP)	Total Range (AP)	SD Displacement (ML)	Total Range (ML)	Total Area	Maximum Radius	Trace Length
RMS Smartph (AP)	**0.999****	-	0.486*	0.788**	-	-	-	0.737**	0.621**
RMS Smartph (ML)	-	**0.920****	-	-	0.692**	0.630**	-	0.545**	0.713**
RMS Acc (AP)	-	-	0.492*	0.789**	-	-	-	0.732**	0.620**
RMS Acc (ML)	-	-	-	-	0.669**	0.568**	-	0.422*	0.672**
Total Displacement Smartph(Integration)	-	-	0.362**	0.449**	0.293**	0.317**	0.359**	0.348**	0.200**
Total Displacement Acc (Integration)	-	-	0.342**	0.377**	0.299**	0.325**	0.343**	0.322**	0.212**
Total Displacement Smartph(Pendulum)	-	-	0.493**	0.560**	0.449**	0.465**	0.537**	0.553**	0.298**
Total Displacement Acc (Pendulum)	-	-	0.512**	0.580**	0.479**	0.490**	0.565**	0.567**	0.340**

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed); Correlations (r-value) were considered Perfect (1.00), Very Strong (0.8 to 0.99), Moderate (0.6 to 0.79), Fair (0.3 to 0.59), Poor (0.1 to 0.29), and None (0) [47].
Smartph= Smartphone; Acc= Accelerometer; AP= Anteroposterior; ML= Mediolateral; Integration= Double Integration Method; Pendulum= Inverted Pendulum Method.

The agreement between measures (Smartphone x Accelerometer) was tested by the intra-class correlation coefficient (ICC) with a 95% confidence interval. An interaction was found with an ICC for the RMS AP of 0.996 (CI 95% = 0.995 - 0.997) and for RMS ML of 0.969 (CI 95% = 0.960 - 0.976) (Table 5).

Table 5 - the intra-class correlation coefficient (ICC) with a 95% confidence interval between the acceleration data from both devices' measurements for AP and ML.

Intraclass Correlation Coefficient

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0	
		Lower Bound	Upper Bound	Value	Sig
Smartph (AP) x Acc (AP)	0.996	0.995	0.997	480.697	0.000
Smartph (ML) x Acc (ML)	0.969	0.960	0.976	63.424	0.000

Smartph= Smartphone; Acc= Accelerometer; AP= Anteroposterior; ML= Mediolateral

Discussion

This work evaluated the ability of inertial sensors from a Smartphone to measure acceleration data during balance tasks through a correlation with a *Gold Standard Accelerometer*. The outcomes show a strong correlation and agreement measurements between the systems (Smartphone x Accelerometer) for the RMS values. These results are in accordance with previous studies that used acceleration signals from other devices rather than a Smartphone or when evaluated (correlated) by other kinematic methods [15,17,22,49]. For the force plate balance correlations, the inverted pendulum model showed better results, although the magnitude of the parameter *Total Displacement* by both models was inconsistent compared to the magnitude of COP displacement measurements.

Bland-Altmann's analysis demonstrated the Smartphone ability to accurately capture acceleration data at different tasks when compared to a gold standard acceleration device. Visual observation of the scatter plots allows the evaluation of the global agreement between two measurements. When the variability of the differences is related only to analytical imprecision, the mean differences should be none [50]. The closeness to the zero lines of the values plotted indicates these reduced differences [51]. The majority of the RMS values within limits, defined as mean ± 2 standard deviations, shows a good agreement between the measurements and reinforces the possibility of using the mobile device as an acceleration acquisition tool. Those results encourage the use of Smartphone's motion sensors for clinical purposes, whether as a tool for balance measurement by self-management or health practitioners' evaluations.

Evidence is already consistent about the use of inertial systems to measure more dynamic, higher range of motion, or cyclic and faster movements [4,9,14,52]. For these approaches, the coherency of the method is more evident due to the physics characteristics of inertial patterns. It has been widely studied by researchers and even incorporated into the essential functions of various models of smartphones for movement recognition and frequently used for mHealth purposes [10,23]. For quasi-static protocols of healthy individuals, the magnitude of the oscillations, among other specificities of the biological signal, makes this scenery different. Some aspects influence the accuracy of mobile inertial sensors and have been described by previous works. The sensor position and the fixation method, operation system, and power of processing, the total temporal window of analysis, floating acquisition rate, body position, and tasks chosen are critical, to mention a few [4,7,31]. Acceleration signals are also known to be susceptible to

bias and errors [4,23], and despite that, our results have shown to be consistent, except for the *Total Displacement,* suggesting that the protocol was not susceptible to these drawbacks for this specific device.

Force plates are a long-established objective way to test postural control found in the literature, and yet there is still no definitive consensus on the best way to describe stability [13,42]. COP measurements, however, like acceleration data devices, are both not a direct measurement of postural balance. COP is the measurement of forces and inertial moments that are applied on the surface and can be assumed as a combination of neuromuscular responses to the body's center of mass displacement [13]. The fair to moderate correlation with a postural balance evaluating tool should encourage the development of more sensitive ways to characterize stability with acceleration from trunk measurements, which directly correlates to the center of mass displacement during quiet standing posture [35].

The Smartphone data compared to the force plate balance parameters in this study shown fair to moderate correlations for the RMS amplitude at the AP and ML directions for both data processing models (Double Integration and Inverted Pendulum). Among the time-dependent variables, the RMS amplitude in Ap and ML is the most commonly reported variable representing stability and express the variability in the signal [24,35]. For inertial data measurement, it has been proved to be a valid and sensitive parameter demonstrating its reliability when compared to variables do COP with characteristics of dispersion [9,11]. The methods of double numerical integration of acceleration, although of controversial use on balance and gait methodologies had lower correlations than the inverted pendulum, and it has been described in the literature, and it was not an unexpected result [36,37].

Some limitations have to be stated about this work for prospects. The closed together foot position was chosen to favor the use of the inverted pendulum model, which is more sensitive for movements on the sagittal plane [12,41] and ankle strategies of balance control [39]. The intention was to simplify a self-orientated position which could be accessed with minimum assistance or supervision. Whether these feet position would be feasible due to security reasons for individuals who are not within normal balance bounding, is still a doubt and is a matter that should be addressed. The flexion-extension movements of the trunk captured by sensors, even though being of small magnitude, have to be considered as a limitation to the model chosen [37]. The synchronization method used in the post-processing analysis was not statistically evaluated for errors, although it was considered valid, and apparently, did not impair the results.

For future studies, we propose the investigation of more heterogeneous samples, the association of other risk factors, the exploration of dynamic tasks, and the limits of stability. Different normalization methods should be investigated as well as other parameters of data processing rather than RMS, which could approximate the differences found between force plate results from acceleration results.

Inertial sensor technology is being recognized for breaking old paradigms of human motion assessments. Smartphone adoption is a pervasive habit and seems to be with irreducible grow. Healthcare applications have been changing individuals' and practitioners' habitual routines, given new strategies for disease management. Acceleration data appears to be reliable for further investigations on correlations to trunk stability and balance impairments helping, for instance, on the development of protocols to train, maintain or regain stability but mainly for assessing balance control. Research on other devices should be encouraged and would contribute to strengthening the method assuring its general use. Acceleration cut off points and bounds of normality compared to other populations would be of use, gathering normative data and perhaps detecting early signs of losing posture ability and risk of falls.

Conclusion

The experimental data from the inertial sensors of the Smartphone highly correlated to an accepted value of a gold standard commercial device and was found to be a reliable acceleration-based measurement for basic balance tasks. The balance parameters with dispersion characteristics assessed by a Force Plate when compared to both acceleration devices presented significant correlations to the RMS acceleration values, being of low to moderate strength when an inverted pendulum model was applied and with lower and inconsistent results for the double integration method.

Author Contributions: A.S.P. (Alexandre S. Pinho) conceived the idea, analyzed the data, and wrote the manuscript; T.B. worked on the data processing methods and wrote the manuscript; M.A.Z. Verified the analytical methods and reviewed the manuscript; A.S.P. (Aline S. Pagnussat) helped to write the first draft; E.M.H. proposed the methods approach and together with A.S.P. (Aline S. Pagnussat) reviewed the manuscript and supervised the project. All authors discussed the results and contributed to the final manuscript.

Acknowledgments: We would like to thank the statistician Cristiane Bündchen of the NUPESQ/UFCSPA Núcleo de Apoio ao Pesquisador for the support at the statistical analysis. Additionally, we would like to thank Dr. Aluisio Octavio Vargas Avila for providing the accelerometer for the experimental setup.

Funding: This study was partially financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Brasília, DF, Brazil), finance Code 001. The authors would like to thank the research funding agency Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Brasília, DF, Brazil) for the scholarship granted [88881.135564/2016-01] to Alexandre S.P. and for his Ph.D. scholarship.

Conflicts of Interest: The authors have no conflict of interest to declare.

References

1. *WHO global report on falls prevention in older age*; World Health Organization, Ed.; World Health Organization: Geneva, Switzerland, 2008; ISBN 978-92-4-156353-6.
2. Mangram, A.; Dzandu, J. Why Elderly Patients with Ground Level Falls Die Within 30 Days And Beyond? *J Gerontol Geriatr Res* **2016**, *05*.
3. Allen, C.J.; Hannay, W.M.; Murray, C.R.; Straker, R.J.; Hanna, M.M.; Meizoso, J.P.; Ray, J.J.; Livingstone, A.S.; Schulman, C.I.; Namias, N.; et al. Causes of death differ between elderly, and adult falls: *Journal of Trauma and Acute Care Surgery* **2015**, *79*, 617–621.
4. del Rosario, M.; Redmond, S.; Lovell, N. Tracking the Evolution of Smartphone Sensing for Monitoring Human Movement. *Sensors* **2015**, *15*, 18901–18933.
5. Roeing, K.L.; Hsieh, K.L.; Sosnoff, J.J. A systematic review of balance and fall risk assessments with mobile phone technology. *Archives of Gerontology and Geriatrics* **2017**, *73*, 222–226.
6. Public Health Agency of Canada *Seniors' falls in Canada.*; 2014; ISBN 978-1-100-23261-4.
7. Pinho, A.S.; Salazar, A.P.; Hennig, E.M.; Spessato, B.C.; Domingo, A.; Pagnussat, A.S. Can We Rely on Mobile Devices and Other Gadgets to Assess the Postural Balance of Healthy Individuals? A Systematic Review. *Sensors (Basel)* **2019**, *19*.
8. Johnston, W.; O'Reilly, M.; Argent, R.; Caulfield, B. Reliability, Validity and Utility of Inertial Sensor Systems for Postural Control Assessment in Sports Science and Medicine Applications: A Systematic Review. *Sports Med* **2019**, *49*, 783–818.
9. Hubble, R.P.; Naughton, G.A.; Silburn, P.A.; Cole, M.H. Wearable sensor use for assessing standing balance and walking stability in people with Parkinson's disease: a systematic review. *PloS one* **2015**, *10*, e0123705.
10. Changizi, M.; Kaveh, M.H. Effectiveness of the mHealth technology in improvement of healthy behaviors in an elderly population—a systematic review. *mHealth,* **2017**, *3*, 51–51.
11. Moe-Nilssen, R. Test-retest reliability of trunk accelerometry during standing and walking. *Archives of physical medicine and rehabilitation* **1998**, *79*, 1377–1385.
12. Winter, D.A.; Patla, A.E.; Prince, F.; Ishac, M.; Gielo-Perczak, K. Stiffness Control of Balance in Quiet Standing. *Journal of Neurophysiology* **1998**, *80*, 1211–1221.
13. Duarte, M.; Zatsiorsky, V. 2 Control of Equilibrium in Humans: 3 Sway over Sway. *Motor Control* 24.
14. Mayagoitia, R.E.; Lötters, J.C.; Veltink, P.H.; Hermens, H. Standing balance evaluation using a triaxial accelerometer. *Gait Posture,* **2002**, *16*, 55–59.

15. Ozinga, S.J.; Alberts, J.L. Quantification of postural stability in older adults using mobile technology. *Experimental Brain Research,* **2014**, *232*, 3861–3872.
16. Patterson, J.A.; Amick, R.Z.; Thummar, T.; Rogers, M.E. Validation of measures from the smartphone sway balance application: a pilot study. *Int J Sports Phys Ther* **2014**, *9*, 135–139.
17. Kosse, N.M.; Caljouw, S.; Vervoort, D.; Vuillerme, N.; Lamoth, C.J.C. Validity and Reliability of Gait and Postural Control Analysis Using the Tri-axial Accelerometer of the iPod Touch. *Annals of Biomedical Engineering* **2015**, *43*, 1935–1946.
18. Hou, Y.-R.; Chiu, Y.-L.; Chiang, S.-L.; Chen, H.-Y.; Sung, W.-H. Feasibility of a smartphone-based balance assessment system for subjects with chronic stroke. *Computer Methods and Programs in Biomedicine* **2018**, *161*, 191–195.
19. Alberts, J.L.; Thota, A.; Hirsch, J.; Ozinga, S.; Dey, T.; Schindler, D.D.; Koop, M.M.; Burke, D.; Linder, S.M. Quantification of the Balance Error Scoring System with Mobile Technology: *Medicine & Science in Sports & Exercise* **2015**, *47*, 2233–2240.
20. Linder, S.M.; Koop, M.M.; Ozinga, S.; Goldfarb, Z.; Alberts, J.L. A Mobile Device Dual-Task Paradigm for the Assessment of mTBI. *Military Medicine,* **2019**, *184*, 174–180.
21. Ozinga, S.J.; Linder, S.M.; Alberts, J.L. Use of Mobile Device Accelerometry to Enhance Evaluation of Postural Instability in Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation* **2017**, *98*, 649–658.
22. Hsieh, K.L.; Roach, K.L.; Wajda, D.A.; Sosnoff, J.J. Smartphone technology can measure postural stability and discriminate fall risk in older adults. *Gait & Posture* **2019**, *67*, 160–165.
23. Luinge, H.J.; Veltink, P.H. Measuring orientation of human body segments using miniature gyroscopes and accelerometers. *Med. Biol. Eng. Comput.* **2005**, *43*, 273–282.
24. Whitney, S.L.; Roche, J.L.; Marchetti, G.F.; Lin, C.-C.; Steed, D.P.; Furman, G.R.; Musolino, M.C.; Redfern, M.S. A comparison of accelerometry and center of pressure measures during computerized dynamic posturography: A measure of balance. *Gait Posture,* **2011**, *33*, 594–599.
25. Tacconi, C.; Mellone, S.; Chiari, L. Smartphone-Based Applications for Investigating Falls and Mobility. In Proceedings of the Proceedings of the 5th International ICST Conference on Pervasive Computing Technologies for Healthcare; IEEE: Dublin, Republic of Ireland, 2011.
26. Memória, C.M.; Yassuda, M.S.; Nakano, E.Y.; Forlenza, O.V. Brief screening for mild cognitive impairment: validation of the Brazilian version of the Montreal cognitive assessment: MoCA validation in Brazil. *Int J Geriatr Psychiatry* **2013**, *28*, 34–40.

27. Tinetti, M.E.; Richman, D.; Powell, L. Falls Efficacy as a Measure of Fear of Falling. *Journal of Gerontology* **1990**, *45*, P239–P243.
28. Vellas, B.J.; Wayne, S.J.; Romero, L.; Baumgartner, R.N.; Rubenstein, L.Z.; Garry, P.J. One-Leg Balance Is an Important Predictor of Injurious Falls in Older Persons. *Journal of the American Geriatrics Society* **1997**, *45*, 735–738.
29. Podsiadlo, D.; Richardson, S. The Timed "Up & Go": A Test of Basic Functional Mobility for Frail Elderly Persons. *Journal of the American Geriatrics Society* **1991**, *39*, 142–148.
30. Pinsault, N.; Vuillerme, N. Test-retest reliability of centre of foot pressure measures to assess postural control during unperturbed stance. *Medical Engineering & Physics* **2009**, *31*, 276–286.
31. Scoppa, F.; Capra, R.; Gallamini, M.; Shiffer, R. Clinical stabilometry standardization. *Gait & Posture* **2013**, *37*, 290–292.
32. Juras, G.; Słomka, K.; Fredyk, A.; Sobota, G.; Bacik, B. Evaluation of the Limits of Stability (LOS) Balance Test. *Journal of Human Kinetics* **2008**, *19*, 39–52.
33. Holbein-Jenny, M.A.; McDermott, K.; Shaw, C.; Demchak, J. Validity of functional stability limits as a measure of balance in adults aged 23–73 years. *Ergonomics,* **2007**, *50*, 631–646.
34. Holbein, M.A.; Chaffin, D.B. Stability Limits In Extreme Postures: Effects Of Load Positioning, Foot Placement, and Strength. *Hum Factors,* **1997**, *39*, 456–468.
35. Williams, J.M.; Dorey, C.; Clark, S.; Clark, C. The within-day and between-day reliability of using sacral accelerations to quantify balance performance. *Physical Therapy in Sport* **2016**, *17*, 45–50.
36. Thong, Y.K.; Woolfson, M.S.; Crowe, J.A.; Hayes-Gill, B.R.; Jones, D.A. Numerical double integration of acceleration measurements in noise. *Measurement* **2004**, *36*, 73–92.
37. Moe-Nilssen, R. A new method for evaluating motor control in gait under real-life environmental conditions. Part 2: Gait analysis. *Clinical Biomechanics,* **1998**, *13*, 328–335.
38. Morasso, P.; Cherif, A.; Zenzeri, J. Quiet standing: The Single Inverted Pendulum model is not so bad after all. *PLoS One* **2019**, *14*.
39. Winter, D.A.; Patla, A.E.; Ishac, M.; Gage, W.H. Motor mechanisms of balance during quiet standing. *Journal of Electromyography and Kinesiology* **2003**, *13*, 49–56.
40. Winter, D.A. Human balance and posture control during standing and walking. *Gait & posture,* **1995**, *3*, 193–214.
41. Winter, D.A.; Prince, F.; Frank, J.S.; Powell, C.; Zabjek, K.F. Unified theory regarding A/P and M/L balance in quiet stance. *Journal of Neurophysiology* **1996**, *75*, 2334–2343.

42. Kapteyn, T.S.; Bles, W.; Njiokiktjien, C.; Kodde, L.R.; Massen, C.C.; Mol, J.N.M. Standardization in platform stabilometry being a part of posturography. *Agressologie: revue internationale de physio-biologie et de pharmacologie appliquees aux effets de l'agression* **1983**, *24*, 321–326.
43. Prieto, T.E.; Myklebust, J.B.; Hoffmann, R.G.; Lovett, E.G.; Myklebust, B.M. Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Transactions on Biomedical Engineering* **1996**, *43*, 956–966.
44. Similä, H.; Immonen, M.; Ermes, M. Accelerometry-based assessment, and detection of early signs of balance deficits. *Computers in Biology and Medicine* **2017**, *85*, 25–32.
45. Zou, G.Y. Sample size formulas for estimating intraclass correlation coefficients with precision and assurance. *Statist. Med.* **2012**, *31*, 3972–3981.
46. Mancini, M.; Horak, F.B.; Zampieri, C.; Carlson-Kuhta, P.; Nutt, J.G.; Chiari, L. Trunk accelerometry reveals postural instability in untreated Parkinson's disease. *Parkinsonism & Related Disorders,* **2011**, *17*, 557–562.
47. Akoglu, H. User's guide to correlation coefficients. *Turk J Emerg Med* **2018**, *18*, 91–93.
48. Chan, Y.H.; B, B.; Chan, Y.H.; Biostatistics, H.O.; Chan, Y.H. Vaccine Clinical Trials. In Proceedings of the in Encyclopedia of Biopharmaceutical Statistics, 2nd Edition, Marcel Dekker; 2003; pp. 1005–1022.
49. Alberts, J.L.; Hirsch, J.R.; Koop, M.M.; Schindler, D.D.; Kana, D.E.; Linder, S.M.; Campbell, S.; Thota, A.K. Using Accelerometer and Gyroscopic Measures to Quantify Postural Stability. *Journal of Athletic Training* **2015**, *50*, 578–588.
50. Giavarina, D. Understanding Bland Altman analysis. *Biochem Med (Zagreb)* **2015**, *25*, 141–151.
51. Bland, J.M.; Altman, D.G. STATISTICAL METHODS FOR ASSESSING AGREEMENT BETWEEN TWO METHODS OF CLINICAL MEASUREMENT. 9.
52. Milosevic, M.; Jovanov, E.; Milenkovic, A. Quantifying Timed-Up-and-Go test: A smartphone implementation. In Proceedings of the 2013 IEEE International Conference on Body Sensor Networks; IEEE: Cambridge, MA, USA, 2013; pp. 1–6.

5. CONSIDERAÇÕES FINAIS

Os estudos provenientes desta tese foram elaborados com o objetivo de avaliar a capacidade de sensores inerciais de *Smartphones* e outros equipamentos móveis para a avaliação do equilíbrio postural de indivíduos saudáveis e idosos. A possibilidade de correlacionar as oscilações relacionadas ao equilíbrio postural que resultaram deste trabalho, permite a prospecção da criação de protocolos que forneçam parâmetros de normalidade e limites de estabilidade para a comparação com outras populações.

No estudo 1, uma revisão sistemática reuniu dados sobre as características dos principais protocolos e variáveis capazes de fornecer informações sobre o equilíbrio. Foi visto que há uma heterogeneidade em relação à qualidade dos trabalhos bem como na opção dos métodos para validação dos dados, o que limita a sua integral comprovação e aceitação. As vantagens e desvantagens destes estudos foram destacadas e ratificaram o uso da metodologia do estudo 2, indicando a melhor escolha para o método de processamento dos sinais, tarefas e demais procedimentos utilizados no protocolo de equilíbrio com a tecnologia de sensores inercias do *Smartphone* em questão.

A partir dos dados experimentais foi possível concluir que os valores de aceleração de um *Smartphone* (iPhone 7) se correlacionam fortemente com um instrumento padrão ouro de comparação (Acelerômetro), apresentando uma alta concordância entre as medidas. Quando comparadas variáveis com características de dispersão dos dados de equilíbrio de uma plataforma de força com os valores de aceleração, foram encontradas correlações de baixas a moderadas utilizando um modelo de pêndulo invertido.

Nesse trabalho, foi verificado que a tecnologia utilizada é promissora graças à evolução dos sensores, sua sensibilidade e capacidade computacional dos telefones. A técnica que se apresenta como uma alternativa de baixo custo, podendo ser utilizada pelos próprios usuários e se mostra capaz de ser incorporada como método de avaliação clínico complementar, desde que os procedimentos de coleta obedeçam a padrões definidos de acordo com a particularidade das características de equilíbrio da população em questão.

6. ANEXOS

6.1 ANEXO I: PARECER CONSUBSTANCIADO DO COMITÊ DE ÉTICA EM PESQUISA

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Uso de Smartphones na avaliação clínica do equilíbrio

Pesquisador: ALINE DE SOUZA PAGNUSSAT

Área Temática:

Versão: 2

CAAE: 88790418.2.0000.5345

Instituição Proponente: Universidade Federal de Ciências da Saúde de Porto Alegre

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.769.754

Apresentação do Projeto:

As consequências das quedas especialmente na população idosa chamam a atenção de pesquisadores para o desenvolvimento de estratégias de prevenção. Métodos quantitativos utilizados para avaliar padrões característicos de postura, seja ela normal ou patológica, são onerosos, altamente complexos e restritos a serviços privados. Atualmente os Smartphones têm provado possuir confiabilidade correlacionável a instrumentos convencionais, mostrando-se uma técnica promissora. O objetivo deste trabalho é comparar os resultados de sistemas considerados "padrão ouro" na avaliação do movimento humano, com os resultados obtidos por sensores inerciais de um telefone celular (Smartphone) a fim de avaliar o equilíbrio e a estabilidade postural de 100 participantes distribuídos em grupos de indivíduos hígidos, indivíduos com dor lombar inespecífica, indivíduos com doença de Parkinson e indivíduos com histórico de Acidente Vascular Cerebral. O comportamento das variáveis espaço-temporais obtidas, será correlacionado por meio dos dados de posição do centro de massa, centro de pressão e aceleração. Testes clínicos subjetivos de equilíbrio, sensibilidade plantar associados a dados cinéticos e cinemáticos de equilíbrio, resultados do Time up Go Test (TUG), a eletromiografia dos músculos dos membros inferiores, e ao movimento ocular serão avaliados utilizando um protocolo adaptado em que o indivíduo deverá permanecer em pé durante 40s em três coletas na condição de (a) Olhos abertos, (b) Olhos fechados e de (c) Olhos em movimento síncrono. Nossa hipótese de trabalho está fundamentada em resultados prévios na literatura com o uso de sensores comerciais, os quais sugerem que os Smartphones podem possuir sensibilidade e acuidade necessárias para a avaliação clínica do equilíbrio.

Objetivo da Pesquisa:

Objetivo Primário:

Avaliar o equilíbrio estático de indivíduos hígidos, indivíduos com dor lombar inespecífica, indivíduos com doença de Parkinson e indivíduos com histórico de AVC com tecnologia de sensores inerciais através de um *Smarphone*.

Objetivo Secundário:

- Descrever as correlações entre diferentes sistemas de medida dos principais parâmetros quantitativos e qualitativos do equilíbrio:

•Verificar as correlações entre dados de um aplicativo para telefone celular (Smartphone) e sistemas “padrão ouro” de análise de movimento e equilíbrio (acelerometria, plataformas de força e cinemetria).
•Descrever o comportamento das variáveis espaço-temporais em posição ortostática, correlacionando dados de posição do centro de massa e centro de pressão;
•Descrever as características do comportamento das variáveis espaço-temporais nos diferentes grupos.

Avaliação dos Riscos e Benefícios:

Riscos: Este estudo não possui testes invasivos e não ocasionará riscos aos participantes, a não ser eventual desconforto relacionado à duração total dos

testes. Poderá ser necessária à raspagem (tricotomia) de três pequenas áreas (1,5cm2) dos pelos das pernas para o posicionamento dos eletrodos, o que pode provocar uma irritação cutânea ou mesmo algum desconforto devido aos eletrodos autocolantes utilizados. Poderá haver algum desconforto ou dor articular por permanecer em pé durante o tempo das tarefas (aproximadamente 15 minutos). Nestes casos, ou no aparecimento de qualquer outro desconforto, os procedimentos serão imediatamente interrompidos, sendo imediatamente tomadas as medidas necessárias. Apesar de todas as precauções de segurança, do auxílio direto dos pesquisadores na orientação das posturas e na condução da pesquisa no ambiente dos testes, os desconfortos e riscos de quedas são considerados mínimos, mas existem. Por este motivo, os indivíduos serão perguntados antes e durante cada tarefa se “acredita que consegue realizar a tarefa” e se há algum desconforto na realização da tarefa proposta, como dor articular por permanecer em pé, ou mesmo alguma irritação cutânea devido aos eletrodos utilizados, os procedimentos serão interrompidos. Intervalos de descanso serão permitidos de acordo com a sensação de esforço individual de cada participante. Os indivíduos não são obrigados a realizar nenhuma tarefa.

Caso não haja certeza da resposta ou não se sintam confiantes para realizar a atividade proposta, serão encorajados a não realizar a tarefa.

Benefícios: Como benefício, os resultados imediatos da pesquisa indicarão as condições de estabilidade e equilíbrio do indivíduo e seu risco provável de quedas. Precauções de segurança quanto ao risco de quedas durante o teste serão tomados com auxílio direto dos pesquisadores na orientação das posturas e no manejo das situações no perímetro dos testes.

Comentários e Considerações sobre a Pesquisa:

O projeto possui relevância pois busca avaliar a utilização de tecnologia disponível em smartphones em comparação com métodos padrão ouro, de maior custo e de acessibilidade mais restrita que a disponível em smartphones, que caso se comprove viável e confiável possibilitará benefícios a curto prazo sobre a qualidade de vida da população idosa.

Considerações sobre os Termos de apresentação obrigatória:

Todos os termos apresentados. Ajustes no TCLE devem ser realizados conforme descrição a seguir: NO TCLE, iniciar o documento pelo título "Termo de consentimento livre e esclarecido (TCLE)"; todo texto anterior deve ser excluído. Uniformizar a cor do texto, eliminando destaques (facilitando a revisão) mas que não devem aparecer no documento final.

Recomendações:

Ajuste no documento final do TCLE.

Conclusões ou Pendências e Lista de Inadequações:

Ajuste no TCLE.

Considerações Finais a critério do CEP: Encaminhar ao CEP nova versão do TCLE para assinatura de aprovação antes do início do projeto.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1126494.pdf	12/06/2018 17:05:55		Aceito
Projeto Detalhado / Brochura	Projeto_Balance_12_junho.docx	12/06/2018 17:05:02	ALINE DE SOUZA PAGNUSSAT	Aceito
Investigador	Projeto_Balance_12_junho.docx	12/06/2018 17:05:02	ALINE DE SOUZA PAGNUSSAT	Aceito
Outros	Carta_Resposta_CEP.pdf	12/06/2018 17:01:10	ALINE DE SOUZA PAGNUSSAT	Aceito
Brochura Pesquisa	Projeto_Balance_12_junho.pdf	12/06/2018 16:56:04	ALINE DE SOUZA PAGNUSSAT	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_12_junho.pdf	12/06/2018 16:54:34	ALINE DE SOUZA PAGNUSSAT	Aceito
Outros	Termo_de_Confidencialidade.pdf	02/05/2018 12:20:14	ALINE DE SOUZA PAGNUSSAT	Aceito
Outros	termo_compromisso_relatorio.pdf	02/05/2018 12:19:48	ALINE DE SOUZA PAGNUSSAT	Aceito
Declaração de Instituição e Infraestrutura	termo_auencia_Laboratorio.pdf	02/05/2018 12:18:00	ALINE DE SOUZA PAGNUSSAT	Aceito
Folha de Rosto	Folha_de_rosto.pdf	02/05/2018 12:15:12	ALINE DE SOUZA PAGNUSSAT	Aceito

Situação do Parecer:

Aprovado

Necessita Apreciação da CONEP:

Não

PORTO ALEGRE, 13 de Julho de 2018

Assinado por:

Luciane Dalcanale Moussalle (Coordenador)

6.2 ANEXO II: NORMAS PARA SUBMISSÃO NO PERIÓDICO "SENSORS"

Manuscript Submission Overview

Types of Publications

Sensors have no restrictions on the length of manuscripts, provided that the text is concise and comprehensive. Full experimental details must be provided so that the results can be reproduced. *Sensors* require that authors publish all experimental controls and make full datasets available where possible (see the guidelines on Supplementary Materials and references to unpublished data).

Manuscripts submitted to *Sensors* should neither be published before nor be under consideration for publication in another journal. The main article types are as follows:

Articles: Original research manuscripts. The journal considers all original research manuscripts provided that the work reports scientifically sound experiments and provides a substantial amount of new information. Authors should not unnecessarily divide their work into several related manuscripts, although Short *Communications* of preliminary, but significant, results will be considered. Quality and impact of the study will be considered during peer review.

Reviews: These provide concise and precise updates on the latest progress made in a given area of research. Systematic reviews should follow the PRISMA guidelines.

Submission Process

Manuscripts for *Sensors* should be submitted online at susy.mdpi.com The submitting author, who is generally the corresponding author, is responsible for the manuscript during the submission and peer-review process. The submitting author must ensure that all eligible co-authors have been included in the author list (read the criteria to qualify for authorship) and that they have all read and approved the submitted version of the manuscript. To submit your manuscript, register, and log in to the submission website. Once you have registered, click here to go to the submission form for *Sensors*. All co-authors can see the manuscript details in the submission system if they register and log in using the e-mail address provided during manuscript submission.

Accepted File Formats

Authors must use the Microsoft Word template or LaTeX template to prepare their manuscript. Using the template file will substantially shorten the time to complete copy-editing and publication of accepted manuscripts. The total amount of data for all files must not exceed 120 MB. If this is a problem, please contact the editorial office sensors@mdpi.com. Accepted file formats are:

Microsoft Word: Manuscripts prepared in Microsoft Word must be converted into a single file before submission. When preparing manuscripts in Microsoft Word, the *Sensors* Microsoft Word template file must be used. Please insert your graphics (schemes, figures, *etc.*) in the main text after the paragraph of its first citation.

LaTeX: Manuscripts prepared in LaTeX must be collated into one ZIP folder (include all source files and images, so that the Editorial Office can recompile the submitted PDF). When preparing manuscripts in LaTeX, please use the *Sensors* LaTeX template files. You can now also use the online application writeLaTeX to submit articles directly to *Sensors*. The MDPI LaTeX template file should be selected from the writeLaTeX template gallery.

Supplementary files: Maybe any format, but it is recommended that you use common, non-proprietary formats where possible (see below for further details).

Cover Letter

A cover letter must be included with each manuscript submission. It should be concise and explain why the content of the paper is significant, placing the findings in the context of existing work and why it fits the scope of the journal. Confirm that neither the manuscript nor any parts of its content are currently under consideration or published in another journal. Any prior submissions of the manuscript to MDPI journals must be acknowledged. The names of proposed and excluded reviewers should be provided in the submission system, not in the cover letter.

Note for Authors Funded by the National Institutes of Health (NIH)

This journal automatically deposits papers to PubMed Central after the publication of an issue. Authors do not need to separately submit their papers through the NIH Manuscript Submission System (NIHMS, http://nihms.nih.gov/).

Manuscript Preparation

General Considerations

Research manuscripts should comprise:

Front matter: Title, Author list, Affiliations, Abstract, Keywords

Research manuscript sections: Introduction, Materials and Methods, Results, Discussion, Conclusions (optional).

Back matter: Supplementary Materials, Acknowledgments, Author Contributions, Conflicts of Interest, References.

Review manuscripts should comprise the front matter, literature review sections, and the back matter. The template file can also be used to prepare the front and back matter of your review manuscript. It is not necessary to follow the remaining structure. Structured reviews and meta-analyses should use the same structure as research articles and ensure they conform to the PRISMA guidelines.

Graphical abstract: Authors are encouraged to provide a graphical abstract as a self-explanatory image to appear alongside with the text abstract in the Table of Contents. Figures should be a high-quality image in any common image format. Note that images displayed online will be up to 11 by 9 cm on screen and the figure should be clear at this size.

Abbreviations should be defined in parentheses the first time they appear in the abstract, main text, and in figure or table captions and used consistently thereafter.

SI Units (International System of Units) should be used. Imperial, US customary and other units should be converted to SI units whenever possible

Equations: If you are using Word, please use either the Microsoft Equation Editor or the MathType add-on. Equations should be editable by the editorial office and not appear in a picture format.

Research Data and supplementary materials: Note that publication of your manuscript implies that you must make all materials, data, and protocols associated with the publication available to readers. Disclose at the submission stage any restrictions on the availability of materials or information. Read the information about Supplementary Materials and Data Deposit for additional guidelines.

Preregistration: Where authors have preregistered studies or analysis plans, links to the preregistration must be provided in the manuscript.

Guidelines and standards: MDPI follows standards and guidelines for certain types of research. See https://www.mdpi.com/editorial_process for further information.

Front Matter

These sections should appear in all manuscript types

Title: The title of your manuscript should be concise, specific, and relevant. It should identify if the study reports (human or animal) trial data, or is a systematic review, meta-analysis or replication study.

Author List and Affiliations: Authors' full first and last names must be provided. The initials of any middle names can be added. The PubMed/MEDLINE standard format is used for affiliations: complete address information including city, zip code, state/province, and country. At least one author should be designated as corresponding author, and his or her email address and other details should be included at the end of the affiliation section. Please read the criteria to qualify for authorship.

Abstract: The abstract should be a total of about 200 words maximum. The abstract should be a single paragraph and should follow the style of structured abstracts but without headings: 1) Background: Place the question addressed in a broad context and highlight the purpose of the study; 2) Methods: Describe briefly the main methods or treatments applied. Include any relevant preregistration numbers, and species and strains of any animals used. 3) Results: Summarize the article's main findings; and 4) Conclusion: Indicate the main conclusions or interpretations. The abstract should be an objective representation of the article: it must not contain results which are not presented and substantiated in the main text and should not exaggerate the main conclusions.

Keywords: Three to ten pertinent keywords need to be added after the abstract. We recommend that the keywords are specific to the article, yet reasonably common within the subject discipline.

Research Manuscript Sections

Introduction: The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance, including specific hypotheses being tested. The current state of the research field should be reviewed carefully, and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the main conclusions. Keep the introduction comprehensible to scientists working outside the topic of the paper.

Materials and Methods: They should be described with sufficient detail to allow others to replicate and build on published results. New methods and protocols should be described in detail, while well-established methods can be briefly described and appropriately cited. Give the name and version of any software used and make clear whether computer code used is available. Include any pre-registration codes.

Results: Provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

Discussion: Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible and limitations of the work highlighted. Future research directions may also be mentioned. This section may be combined with Results.

Conclusions: This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

Patents: This section is not mandatory, but may be added if there are patents resulting from the work reported in this manuscript.

Back Matter

Supplementary Materials: Describe any supplementary material published online alongside the manuscript (figure, tables, video, spreadsheets, etc.). Please indicate the name and title of each element as follows Figure S1: title, Table S1: title, etc.

Acknowledgments: All sources of funding of the study should be disclosed. Clearly, indicate grants that you have received in support of your research work and if you received funds to cover publication costs. Note that some funders will not refund article processing charges (APC) if the funder and grant number are not clearly and correctly identified in the paper. Funding information can be entered separately into the submission system by the authors during submission of their manuscript. Such funding information, if available, will be deposited to FundRef if the manuscript is finally published.

Author Contributions: Each author is expected to have made substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data; or the creation of new software used in the work; or have drafted the work or substantively revised it; AND has approved the submitted version (and version substantially edited by journal staff that involves the author's contribution to the study); AND agrees to be personally accountable for the author's own contributions and for ensuring that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and documented in the literature.
For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.X. and Y.Y.; Methodology, X.X.; Software, X.X.; Validation, X.X., Y.Y. and Z.Z.; Formal Analysis, X.X.; Investigation, X.X.; Resources, X.X.; Data Curation, X.X.; Writing – Original Draft Preparation, X.X.; Writing – Review & Editing, X.X.; Visualization, X.X.; Supervision, X.X.; Project Administration, X.X.; Funding Acquisition, Y.Y.", please turn to the CRediT taxonomy for the term explanation. For more background on CRediT, see here. "Authorship must include and be limited to those who have contributed substantially to the work. Please read the section concerning the criteria to qualify for authorship carefully".

Conflicts of Interest: Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. If there is no conflict of interest, please state, "The authors declare no conflict of interest." Any role of the funding sponsors in the choice of research project; design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results must be declared in this section. *Sensors* does not publish studies funded by the tobacco industry. Any projects funded by pharmaceutical or food industries must pay special attention to the full declaration of funder involvement. If there is no role, please state "The sponsors had no role in the design, execution, interpretation, or writing of the study."

References: References must be numbered in order of appearance in the text (including table captions and figure legends) and listed individually at the end of the manuscript. We recommend preparing the references with a bibliography software package, such as EndNote, ReferenceManager, or Zotero, to avoid typing mistakes and duplicated references. We encourage citations to data, computer code and other citable research material. If available online, you may use reference style 9. below.

Citations and References in Supplementary files are permitted provided that they also appear in the main text and in the reference list.

In the text, reference numbers should be placed in square brackets [ ], and placed before the punctuation; for example [1], [1–3] or [1,3]. For embedded citations in the text with pagination, use both parentheses and brackets to indicate the reference number and page numbers; for example [5] (p. 10). or [6] (pp. 101–105).

The reference list should include the full title, as recommended by the ACS style guide. Style files for Endnote and Zotero are available.

References should be described as follows, depending on the type of work:

Journal Articles:

1. Author 1, A.B.; Author 2, C.D. Title of the article. *Abbreviated Journal Name* Year, *Volume*, page range.

Books and Book Chapters:

2. Author 1, A.; Author 2, B. *Book Title*, 3rd ed.; Publisher: Publisher Location, Country, Year; pp. 154–196.
3. Author 1, A.; Author 2, B. Title of the chapter. In *Book Title*, 2nd ed.; Editor 1, A., Editor 2, B., Eds.; Publisher: Publisher Location, Country, Year; Volume 3, pp. 154–196.

Unpublished work, submitted work, personal communication:

5. Author 1, A.B.; Author 2, C. Title of Unpublished Work. status (unpublished; manuscript in preparation).
   5. Author 1, A.B.; Author 2, C. Title of Unpublished Work. *Abbreviated Journal Name* stage of publication (under review; accepted; in press).

6. Author 1, A.B. (University, City, State, Country); Author 2, C. (Institute, City, State, Country). Personal communication, Year.

Conference Proceedings:

7. Author 1, A.B.; Author 2, C.D.; Author 3, E.F. Title of Presentation. In *Title of the Collected Work* (if available), Proceedings of the Name of the Conference, Location of Conference, Country, Date of Conference; Editor 1, Editor 2, Eds. (if available); Publisher: City, Country, Year (if available); Abstract Number (optional), Pagination (optional).

Thesis:
8. Author 1, A.B. Title of Thesis. Level of Thesis, Degree-Granting University, Location of University, Date of Completion.

Websites:
9. Title of Site. Available online: URL (accessed on Day Month Year).

Unlike published works, websites may change over time or disappear, so we encourage you create an archive of the cited website using a service such as WebCite. Archived websites should be cited using the link provided as follows:

10. Title of Site. URL (archived on Day Month Year).

See the Reference List, and Citations Guide for more detailed information.

Preparing Figures, Schemes, and Tables

File for Figures and Schemes must be provided during submission in a single zip archive and at a sufficiently high resolution (minimum 1000 pixels width/height, or a resolution of 300 dpi or higher). Common formats are accepted; however, TIFF, JPEG, EPS, and PDF are preferred.

Sensors can publish multimedia files in articles or as supplementary materials. Please contact the editorial office for further information.

All Figures, Schemes, and Tables should be inserted into the main text close to their first citation and must be numbered following their number of appearance (Figure 1, Scheme I, Figure 2, Scheme II, Table 1, *etc.*).

All Figures, Schemes, and Tables should have a short explanatory title and caption.

All table columns should have an explanatory heading. To facilitate the copy-editing of larger tables, smaller fonts may be used, but no less than 8 pt. in size. Authors should use the Table option of Microsoft Word to create tables.

Authors are encouraged to prepare figures and schemes in color (RGB at 8-bit per channel). There is no additional cost for publishing full-color graphics.

Supplementary Materials, Data Deposit and Software Source Code

Data Availability

In order to maintain the integrity, transparency and reproducibility of research records, authors must make their experimental and research data openly available either by depositing into data repositories or by publishing the data and files as supplementary information in this journal.

Computer Code and Software

For work where novel computer code was developed, authors should release the code either by depositing in a recognized, public repository or uploading as supplementary information to the publication. The name and version of all software used should be clearly indicated.

Supplementary Material

Additional data and files can be uploaded as "Supplementary Files" during the manuscript submission process. The supplementary files will also be available to the referees as part of the peer-review process. Any file format is acceptable, however, we recommend that common, non-proprietary formats are used where possible.

Unpublished Data

Restrictions on data availability should be noted during submission and in the manuscript. "Data not shown" should be avoided: authors are encouraged to publish all observations related to the submitted manuscript as Supplementary Material. "Unpublished data" intended for publication in a manuscript that is either planned, "in preparation" or "submitted" but not yet accepted, should be cited in the text and a reference should be added in the References section. "Personal Communication" should also be cited in the text and reference added in the References section. (see also the MDPI reference list and citations style guide).

Remote Hosting and Large Data Sets

Data may be deposited with specialized service providers or institutional/subject repositories, preferably those that use the DataCite mechanism. Large data sets and files greater than 60 MB must be deposited in this way. For a list of other repositories specialized in scientific and experimental data, please consult databib.org or re3data.org. The data repository name, link to the data set (URL) and accession number, doi or handle number of the data set must be provided in the paper. The journal Data also accepts submissions of data set papers.

References in Supplementary Files

Citations and References in Supplementary files are permitted provided that they also appear in the reference list of the main text.

Research and Publication Ethics

Research Ethics

Research Involving Human Subjects

When reporting on research that involves human subjects, human material, human tissues, or human data, authors must declare that the investigations were carried out following the rules of the Declaration of Helsinki of 1975 (https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/), revised in 2013. According to point 23 of this declaration, an approval from an ethics committee should have been obtained

before undertaking the research. At a minimum, a statement including the project identification code, date of approval, and name of the ethics committee or institutional review board should be cited in the Methods Section of the article. Data relating to individual participants must be described in detail, but private information identifying participants need not be included unless the identifiable materials are of relevance to the research (for example, photographs of participants' faces that show a particular symptom). Editors reserve the right to reject any submission that does not meet these requirements.

Example of an ethical statement: "All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of XXX (Project identification code)."

A written informed consent for publication must be obtained from participating patients who can be identified (including by the patients themselves). Patients' initials or other personal identifiers must not appear in any images. For manuscripts that include any case details, personal information, and/or images of patients, authors must obtain signed informed consent from patients (or their relatives/guardians) before submitting to an MDPI journal. Patient details must be anonymized as far as possible, e.g., do not mention specific age, ethnicity, or occupation where they are not relevant to the conclusions. A template permission form is available to download. A blank version of the form used to obtain permission (without the patient names or signature) must be uploaded with your submission.

You may refer to our sample form and provide an appropriate form after consulting with your affiliated institution. Alternatively, you may provide a detailed justification of why informed consent is not necessary. For the purposes of publishing in MDPI journals, a consent, permission, or release form should include unlimited permission for publication in all formats (including print, electronic, and online), in sublicensed and reprinted versions (including translations and derived works), and in other works and products under open access license. To respect patients' and any other individual's privacy, please do not send signed forms. The journal reserves the right to ask authors to provide signed forms if necessary.

Research Involving Cell Lines

Methods sections for submissions reporting on research with cell lines should state the origin of any cell lines. For established cell lines the provenance should be stated, and references must also be given to either a published paper or to a commercial source. If previously unpublished *de novo* cell lines were used, including those gifted from another laboratory, details of institutional review board or ethics committee approval must be given, and confirmation of written informed consent must be provided if the line is of human origin.

An example of Ethical Statements:

The HCT116 cell line was obtained from XXXX. The $MLH1^{+}$ cell line was provided by XXXXX, Ltd. The DLD-1 cell line was obtained from Dr. XXXX. The DR-GFP and SA-GFP reporter plasmids were obtained from Dr. XXX and the Rad51K133A expression vector was obtained from Dr. XXXX.

Publication Ethics Statement

Sensors is a member of the Committee on Publication Ethics (COPE). We fully adhere to its Code of Conduct and to its Best Practice Guidelines.

The editors of this journal enforce a rigorous peer-review process together with strict ethical policies and standards to ensure to add high-quality scientific works to the field of scholarly publication. Unfortunately, cases of plagiarism, data falsification, image manipulation, inappropriate authorship credit, and the like, do arise. The editors of *Sensors* take such publishing ethics issues very seriously and are trained to proceed in such cases with a zero-tolerance policy.

Authors wishing to publish their papers in *Sensors* must abide to the following:

Any facts that might be perceived as a possible conflict of interest of the author(s) must be disclosed in the paper prior to submission.

Authors should accurately present their research findings and include an objective discussion of the significance of their findings.

Data and methods used in the research need to be presented in sufficient detail in the paper, so that other researchers can replicate the work.

Raw data should preferably be publicly deposited by the authors before submission of their manuscript. Authors need to at least have the raw data readily available for presentation to the referees and the editors of the journal, if requested. Authors need to ensure appropriate measures are taken so that raw data is retained in full for a reasonable time after publication.

Simultaneous submission of manuscripts to more than one journal is not tolerated.

Republishing content that is not novel is not tolerated (for example, an English translation of a paper that is already published in another language will not be accepted).

If errors and inaccuracies are found by the authors after publication of their paper, they need to be promptly communicated to the editors of this journal so that appropriate actions can be taken. Please refer to our policy regarding publication of publishing addenda and corrections.

Your manuscript should not contain any information that has already been published. If you include already published figures or images, please obtain the necessary permission from the copyright holder to publish under the CC-BY license. For further information, see the Rights and Permissions page.

Plagiarism, data fabrication and image manipulation are not tolerated.

Plagiarism is not acceptable in *Sensors* submissions.

Plagiarism includes copying text, ideas, images, or data from another source, even from your own publications, without giving any credit to the original source.

Reuse of text that is copied from another source must be between quotes and the original source must be cited. If a study's design or the manuscript's structure or language has been inspired by previous works, these works must be explicitly cited.

If plagiarism is detected during the peer review process, the manuscript may be rejected. If plagiarism is detected after publication, we may publish a correction or retract the paper.

Image files must not be manipulated or adjusted in any way that could lead to misinterpretation of the information provided by the original image.

Irregular manipulation includes: 1) introduction, enhancement, moving, or removing features from the original image; 2) grouping of images that should obviously be presented separately (e.g., from different parts of the same gel, or from different gels); or 3) modifying the contrast, brightness or color balance to obscure, eliminate or enhance some information.

If irregular image manipulation is identified and confirmed during the peer review process, we may reject the manuscript. If irregular image manipulation is identified and confirmed after publication, we may correct or retract the paper.

Our in-house editors will investigate any allegations of publication misconduct and may contact the authors' institutions or funders if necessary. If evidence of misconduct is found, appropriate action will be taken to correct or retract the publication. Authors are expected to comply with the best ethical publication practices when publishing with MDPI.

Reviewer Suggestions

During the submission process, please suggest three potential reviewers with the appropriate expertise to review the manuscript. The editors will not necessarily approach these referees. Please provide detailed contact information (address, homepage, phone, e-mail address). The proposed referees should neither be current collaborators of the co-authors nor have published with any of the co-authors of the manuscript within the last five years. Proposed reviewers should be from different institutions to the authors. You may identify appropriate Editorial Board members of the journal as potential reviewers. You may suggest reviewers from among the authors that you frequently cite in your paper.

English Corrections

To facilitate proper peer-reviewing of your manuscript, it is essential that it is submitted in grammatically correct English. Advice on some specific language points can be found here.

If you are not a native English speaker, we recommend that you have your manuscript professionally edited before submission or read by a native English-speaking colleague. This can be carried out by MDPI's English editing service. Professional editing will enable reviewers and future readers to more easily read and assess the content of submitted manuscripts. All accepted manuscripts undergo language editing, however an additional fee will be charged to authors if very extensive English corrections must be made by the Editorial Office: pricing is according to the service here.

Preprints and Conference Papers

Sensors accepts articles that have previously been made available as preprints provided that they have not undergone peer review. A preprint is a draft version of a paper made available online before submission to a journal.

MDPI operates *Preprints*, a preprint server to which submitted papers can be uploaded directly after completing journal submission. Note that *Preprints* operates independently of the journal and posting a preprint does not affect the peer review process. Check the *Preprints* instructions for authors for further information.

Expanded and high-quality conference papers can be considered as articles if they fulfill the following requirements: (1) the paper should be expanded to the size of a research article; (2) the conference paper should be cited and noted on the first page of the paper; (3) if the authors do not hold the copyright of the published conference paper, authors should seek the appropriate permission from the copyright holder; (4) authors are asked to disclose that it is conference paper in their cover letter and include a statement on what has been changed compared to the original conference paper. *Sensors* does not publish pilot studies or studies with inadequate statistical power.

Authorship

MDPI follows the International Committee of Medical Journal Editors (ICMJE) guidelines which state that, in order to qualify for authorship of a manuscript, the following criteria should be observed:

Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND

Drafting the work or revising it critically for important intellectual content; AND

Final approval of the version to be published; AND

Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Those who contributed to the work but do not qualify for authorship should be listed in the acknowledgments. More detailed guidance on authorship is given by the International Council of Medical Journal Editors (ICMJE).

Any change to the author list should be approved by all authors including any who have been removed from the list. The corresponding author should act as a point of contact between the editor and the other authors and should keep co-authors informed and involve them in major decisions about the publication. We reserve the right to request confirmation that all authors meet the authorship conditions.

Reviewers Recommendation

Authors can recommend potential reviewers. Journal editors will check to make sure there are no conflict of interests before contacting those reviewers, and will not consider those with competing interests. Reviewers are asked to declare any conflicts of interest. Authors can also enter the names of potential peer reviewers they wish to exclude from consideration in the peer review of their manuscript, during the initial submission progress. The editorial team will respect these requests so long as this does not interfere with the objective and thorough assessment of the submission.

Editors and Journal Staff as Authors

Editorial independence is extremely important and MDPI does not interfere with editorial decisions.

Editorial staff or editors shall not be involved in the processing their own academic work. Submissions authored by editorial staff/editors will be assigned to at least two independent outside reviewers. Decisions will be made by other editorial board members who do not have conflict of interests with the author. Journal staff are not involved in the processing of their own work submitted to any MDPI journals.

Conflict of Interests

According to The International Committee of Medical Journal Editors, “Authors should avoid entering into agreements with study sponsors, both for-profit and non-profit, that interfere with authors’ access to all of the study’s data or that interfere with their ability to analyze and interpret the data and to prepare and publish manuscripts independently when and where they choose.”

Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. If there is no conflict of interest, please state "The authors declare no conflict of interest." Any role of the funding sponsors in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results must be declared in this section. If there is no role, please state “The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results”.

Editorial Procedures and Peer-Review

Initial Checks

All submitted manuscripts received by the Editorial Office will be checked by a professional in-house *Managing Editor* to determine whether they are properly prepared and whether they follow the ethical policies of the journal. Manuscripts that do not fit the journal's ethics policy or do not meet the standards of the journal will be rejected before peer-review. Manuscripts that are not properly prepared will be returned to the authors for revision and resubmission. After these checks, the *Managing Editor* will consult the journals’ *Editor-in-Chief* or *Associate Editors* to determine whether the manuscript fits the scope of the journal and whether it is scientifically sound. No judgment on the potential impact of the work will be made at this stage. Reject decisions at this stage will be verified by the *Editor-in-Chief*.

Peer-Review

Once a manuscript passes the initial checks, it will be assigned to at least two independent experts for peer-review. A single-blind review is applied, where authors' identities are known to reviewers. Peer review comments are confidential and will only be disclosed with the express agreement of the reviewer.

In the case of regular submissions, in-house assistant editors will invite experts, including recommendations by an academic editor. These experts may also include *Editorial Board members* and Guest Editors of the journal. Potential reviewers suggested by the authors may also be considered. Reviewers should not have published with any of the co-authors during the past five years and should not currently work or collaborate with any of the institutions of the co-authors of the submitted manuscript.

Optional Open Peer-Review

The journal operates optional open peer-review: *Authors are given the option for all review reports and editorial decisions to be published alongside their manuscript. In addition, reviewers can sign their review, i.e., identify themselves in the published review reports.* Authors can alter their choice for open review at any time before publication, however once the paper has been published changes will only be made at the discretion of the *Publisher* and *Editor-in-Chief*. We encourage authors to take advantage of this opportunity as proof of the rigorous process employed in publishing their research. To guarantee an impartial refereeing the names of referees will be revealed only if the referees agree to do so, and after a paper has been accepted for publication.

Editorial Decision and Revision

All the articles, reviews and communications published in MDPI journals go through the peer-review process and receive at least two reviews. The in-house editor will communicate the decision of the academic editor, which will be one of the following:

Accept after Minor Revisions:

The paper is in principle accepted after revision based on the reviewer’s comments. Authors are given five days for minor revisions.

Reconsider after Major Revisions:

The acceptance of the manuscript would depend on the revisions. The author needs to provide a point by point response or provide a rebuttal if some of the reviewer’s comments cannot be revised. Usually, only one round of major revisions is allowed. Authors will be asked to resubmit the revised paper within a suitable time frame, and the revised version will be returned to the reviewer for further comments.

Reject and Encourage Resubmission:

If additional experiments are needed to support the conclusions, the manuscript will be rejected and the authors will be encouraged to re-submit the paper once further experiments have been conducted.

Reject:
The article has serious flaws, and/or makes no original significant contribution. No offer of resubmission to the journal is provided.

All reviewer comments should be responded to in a point-by-point fashion. Where the authors disagree with a reviewer, they must provide a clear response.

Author Appeals

Authors may appeal a rejection by sending an e-mail to the Editorial Office of the journal. The appeal must provide a detailed justification, including point-by-point responses to the reviewers' and/or Editor's comments. The *Managing Editor* of the journal will forward the manuscript and related information (including the identities of the referees) to the Editor-in-Chief, Associate Editor, or Editorial Board member. The academic

Editor being consulted will be asked to give an advisory recommendation on the manuscript and may recommend acceptance, further peer-review, or uphold the original rejection decision. A reject decision at this stage is final and cannot be reversed.

In the case of a special issue, the *Managing Editor* of the journal will forward the manuscript and related information (including the identities of the referees) to the *Editor-in-Chief* who will be asked to give an advisory recommendation on the manuscript and may recommend acceptance, further peer-review, or uphold the original rejection decision. A reject decision at this stage will be final and cannot be reversed.

Production and Publication

Once accepted, the manuscript will undergo professional copy-editing, English editing, proofreading by the authors, final corrections, pagination, and, publication on the www.mdpi.com website.

7. APÊNDICES

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE)

Você está sendo convidada (o) a participar da pesquisa "**Uso de Smartphones na avaliação clínica do equilíbrio**", de responsabilidade dos pesquisadores Aline de Souza Pagnussat e Alexandre Severo do Pinho, do Programa de Pós-graduação em Ciências da Saúde da Universidade Federal de Ciências da Saúde de Porto Alegre (UFCSPA).

Por favor, leia este documento com bastante atenção antes de assiná-lo. Peça orientação quantas vezes for necessário para esclarecer todas as suas dúvidas. A proposta deste Termo de Consentimento Livre e Esclarecido (TCLE) é explicar tudo sobre o estudo e solicitar a sua permissão para participar do mesmo.

Este estudo foi aprovado pelo Comitê de Ética em Pesquisa com Seres Humanos (CEP) da UFCSPA, sob o protocolo **88790418.2.0000.5345.**

Motivo e objetivo do estudo

Você está sendo convidado (a) a participar deste estudo por uma das seguintes razões:

- Você participou de um estudo anterior vinculado ao Laboratório de Reabilitação da Universidade Federal de Ciências da Saúde;
- Você não apresenta doença crônica aparente que altere o equilíbrio;

Objetivo do estudo

O objetivo deste estudo é verificar se um telefone celular é capaz de quantificar o equilíbrio na postura em pé.

Descrição dos procedimentos do estudo

Você poderá fazer parte de um dos grupos descritos a seguir:

(a) Indivíduo hígido (saudável) de 20 a 35 anos;

(b) Indivíduo hígido (saudável) acima de 35 anos;

Avaliações:

As avaliações poderão ser realizadas em um ou dois dias a serem agendados de acordo com a sua disponibilidade e a disponibilidade do laboratório.

Avaliações a serem realizadas em domicílio: (opcional)

No primeiro dia, no tempo máximo de 40 minutos, serão realizados questionários sobre sua saúde e verificar o seu risco de quedas, logo após um teste de força manual (preensão manual) e por fim, avaliações de equilíbrio em postura ereta com o uso de um celular junto a um pequeno dispositivo (acelerômetro) fixados com uma cinta elástica na cintura por 10 minutos.

Avaliações a serem realizadas no laboratório:

Durante a postura ereta, serão realizadas filmagens com o uso do celular, junto a um pequeno dispositivo (acelerômetro) fixado com uma cinta elástica na cintura. Você será perguntado frequentemente sobre alguma dor ou desconforto durante as avaliações. Estes procedimentos na postura ereta serão realizados em 10 minutos, porém o tempo total da sessão será de 70 minutos devido às preparações dos equipamentos.

Possíveis riscos e desconfortos

As avaliações se baseiam em tarefas simples do cotidiano, como permanecer em pé de olhos fechados por 2 minutos, fazer uma volta de 360 graus, pegar um objeto no chão, permanecer em posição ereta com um pé na frente do outro, ou ainda tentar permanecer com apoio de um único pé sem auxílio por alguns segundos.

Em todos os procedimentos você será acompanhado por um pesquisador responsável por sua segurança nas tarefas e capacitado a realizar todas as avaliações. Você será perguntado antes de cada tarefa se "acredita que consegue realizar a tarefa". Você não é obrigado a realizar nenhuma tarefa. No caso de não ter certeza ou não se sentir confiante para realizar, você não precisa realizar a tarefa.

Possíveis benefícios

O possível benefício que você terá ao participar da pesquisa será de realizar uma minuciosa avaliação de equilíbrio que pode identificar possíveis deficiências em sua capacidade de se equilibrar ou ainda de indicar o seu risco de quedas.

Custos pessoais

Você **não** terá despesas pessoais em qualquer fase deste estudo e caso tenha despesas com o deslocamento até o local da pesquisa ou não tenha condições de se deslocar, os valores poderão ser ressarcidos ou um pesquisador responsável irá lhe buscar. **Não** haverá compensação financeira relacionada à sua participação. Esta pesquisa não tem nenhuma finalidade econômica.

Danos relacionados à pesquisa

Não estão previstos danos aos participantes da pesquisa, mas em caso de danos diretamente causados por procedimentos da pesquisa, será garantido o tratamento médico com as medicações necessárias ou tratamento fisioterápico.

Possível desistência

Sua participação neste estudo é totalmente **voluntária**, ou seja, você somente participa se quiser. Você pode desistir da participação em qualquer momento.

Situações para encerramento precoce do estudo

Se for verificada a necessidade de suspender, interromper ou cancelar o estudo antes do previsto por questões técnicas, os motivos para a descontinuação serão informados ao CEP (Comitê de Ética em Pesquisa com Seres Humanos) e o encerramento se dará apenas após autorização deste comitê. Você será imediatamente informado em caso de descontinuação.

Novas Informações

Quaisquer novas informações que possam afetar a sua segurança ou influenciar na sua decisão de continuar participando do estudo serão fornecidas a você por escrito. Se você decidir continuar neste estudo, terá que assinar um novo (revisado) termo de consentimento informado para documentar seu conhecimento sobre novas informações.

Utilização de seus dados pessoais

Todas as informações colhidas e/ou resultados serão analisadas em caráter estritamente científico, mantendo-se a confidencialidade (segredo) de sua identidade a todo o momento, ou seja, em nenhum momento os dados que o identifique serão divulgados.

Seus dados serão utilizados somente para esta pesquisa e ficarão armazenados em um banco de dados pelos pesquisadores durante cinco anos, após, serão devidamente descartados.

Os resultados desta pesquisa serão disponibilizados para publicação, sendo seus resultados favoráveis ou não, contudo, sua identidade não será revelada.

Para maiores informações ou necessitando de alguma ajuda

Em qualquer etapa do estudo você terá acesso aos profissionais responsáveis pela pesquisa para esclarecimento de eventuais dúvidas. Os responsáveis pelo estudo na instituição são: Aline de Souza Pagnussat e Alexandre Severo do Pinho, que poderão ser encontrados na Universidade Federal de Ciências da Saúde, na Rua Sarmento Leite 245, sala 308, nos respectivos telefones: (51)33038776 ou (51)999856114.

Em caso de dúvidas ou preocupações quanto aos seus direitos como participante deste estudo, o (a) senhor (a) pode entrar em contato com o Comitê de Ética em Pesquisa com Seres Humanos (CEP) da UFCSPA através do telefone (51)33038804.

Declaração de consentimento

Concordo em participar, de forma voluntária, do estudo intitulado "**Uso de Smartphones na avaliação clínica do equilíbrio**".

Ficaram claros para mim quais são os propósitos do estudo, os procedimentos a serem realizados, seus desconfortos e riscos, as garantias de confidencialidade e de esclarecimentos permanentes. Tive oportunidade de perguntar sobre o estudo e todas as minhas dúvidas foram esclarecidas. Entendo que estou livre para decidir não participar desta pesquisa, sem nenhum prejuízo ou represália de qualquer natureza podendo de desistir da pesquisa a qualquer momento. Eu autorizo a utilização dos meus registros médicos (prontuário médico) pelo pesquisador, autoridades regulatórias e pelo Comitê de Ética em Pesquisa com Seres Humanos (CEP) da instituição.

Estou ciente que receberei uma cópia deste TCLE assinado por mim, pela pessoa que realizou a discussão sobre o termo de consentimento e quando aplicável pela testemunha e/ou representante legal e entendo que ao assinar este documento, não estou abdicando de nenhum de meus direitos legais.

Assinatura do voluntário

_____

Nome do voluntário (letra de forma)

_____ _____

Assinatura do pesquisador responsável pelo estudo Data

Alexandre Severo do Pinho

Nome do responsável pelo estudo

_____

Data