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ORIGINAL ARTICLE

Reflex activity of pelvic floor muscles during drop landings and mini-trampolining—exploratory study

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Abstract

Introduction Complex functional movements such as jumping typically provoke stress urinary incontinence (SUI) in women. The aim of this study was to investigate pelvic floor muscle (PFM) activity in young, healthy women during jumps to explore their activity characteristics.

Methods Surface electromyography (EMG) from PFMs was measured in 16 healthy women with a tripolar vaginal probe during drop landings from heights of 15, 30 and 45 cm (DL 15, 30, 45) as well as during mini-trampolining with a pace of 90 and 75 jumps per minute (MT 90, 75). Time of foot strike and body weight force (BWF) in % (= ground reaction force, normalised to body weight) was determined by force plates. Root mean square values of the EMG signals were analyzed from 30 ms before to 150 ms after foot strike. Peak activity during maximum voluntary contraction (MVC) was set as 100% for EMG normalization. The PFM onset threshold was determined as the mean of rest activity plus 2 standard deviations. Data were analysed with non-parametric statistical methods.

Results EMG activity during all jumps was above the PFM onset threshold. Mean pre- and reflex activity increased significantly with jumping height ($p < 0.05$) as well as with increasing BWF. The PFM activation pattern of DL was with peak activity of 115–182 %MVC between 34 and 44 ms after foot strike, which was different from MT with peak PFM activity of 85–115 %MVC reached at 133 ms.

Conclusions Jumping and mini-trampolining provoked significant PFM activity in healthy volunteers. The next research step will be to examine the PFM activity of women suffering from SUI during jumps.

Keywords Electromyography · Ground reaction force · High impact · Jump · Stress urinary incontinence

Abbreviations

AM	Abdominal muscle
bpm	Beats per minute
BWF	Body weight force: ground reaction force, normalized to body weight
DL	Drop landing
DL 15, 30, 45	Drop landings from heights of 15, 30 and 45 cm
EMG	Electromyography
GRF	Ground reaction force
IAP	Intraabdominal pressure
MT	Mini-trampolining
MT 90, 75	Mini-trampolining with a pace of 90 and 75 jumps per minute
MVC	Maximum voluntary contraction
% MVC	Maximum voluntary contraction normalised to peak activity
PFM	Pelvic floor muscle
PFMT	Pelvic floor muscle training
RMS	Root mean square
SUI	Stress urinary incontinence
TAS	Tegner activity scale (questionnaire)

Introduction

Stress urinary incontinence (SUI) is defined as "the complaint of involuntary loss of urine on effort or physical exertion (e.g. sporting activities), or on sneezing or coughing" [1] and occurs in 26 to 36 % of the entire population [2, 3]. Due to their medical condition, people who are affected by SUI tend to be

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less active and thus face a greater risk of developing cardiovascular diseases, overweight, diabetes, functional impairment or depression [2]. As there is an interconnection between the waist circumference and the probability of becoming affected by SUI, this may lead to the following vicious circle: the less active people are, the more bodyweight they gain and the more prone to SUI they become [2, 4]. However, also young female athletes performing high-impact sports such as gymnastics, volleyball or dancing are affected by SUI with a prevalence of 25–34% [5]. Further, 80% of elite trampolinists suffer from SUI [6]. Although investigations by MRI and ultrasound show that athletes who practice high-impact sports develop a bigger cross-section of the pelvic floor muscle (PFM) [7, 8], it can be concluded that high-impact sports strengthen the PFMs. According to the urinary incontinence guidelines [9, 10], conservative treatment of SUI focuses on voluntary pelvic floor muscle training (PFMT), and several studies have confirmed the benefit of this exercise method [3, 11]. Ultrasound is commonly used as biofeedback to visualize the bladder neck under voluntary and involuntary PFM activity in the supine or other static positions [12]. Reflex activity of the PFMs is only confirmed during the complex functional movement of running [13, 14]. However, the most important characteristic of PFM function is to contract strongly, rapidly and reflexively during high-impact sporting activities or sneezing and coughing [15, 16]. To the authors' knowledge, PFMT does not yet involve the reflexive function of PFMs apart from the study protocol by Luginbuehl et al. [17], from which the results are still outstanding.

In summary, high-impact sports activities may lead to PFM activity, but they can also lead to SUI. Therefore, the goal of this study was to elucidate reflexive activity characteristics of the PFMs during jumps. First, we hypothezised that PFM activity will be higher during jumps than during rest conditions in the standing position. The second hypothesis was that PFM activity as well as body weight force (BWF) (= ground reaction force, normalized to body weight) will increase with larger jump height, and finally it was unknown if the activation patterns of drop landing (DL) and mini-trampolining (MT) would be similar or completely different.

Methods

Study design

An exploratory cross-sectional study design with experimental measurements was conducted to gain knowledge about the reflex and involuntary activity of PFMs during jumps. The study was approved by the Ethics Committee of the Canton of Bern, Switzerland (KEK; ID 2016-00786).

Participants

Seventeen women were recruited by e-mail from the midwifery and nursing programmes of the Bern University of Applied Sciences or employees of Bern University Hospital and the Cantonal Hospital of Baden. Inclusion criteria were age between 18 and 40 years, nulliparous, healthy, BMI between 18 and 30 kg/m², and the abilities to jump and to understand German. Exclusion criteria were pregnancy, urinary tract or vaginal infections, acute pain, PFM strength < 4 according to the modified Oxford Scale or other conditions that restricted measurements or test activities. Also excluded were women menstruating on the day of measurement. All participants were able to understand and write German and gave written informed consent.

Instrumentation

Because good intrasession reliability of the applied setting had been confirmed earlier during running [22], it was reused with the STIMPON™ tripolar vaginal probe, which was covered by a ProDry tampon™ (Innocept Biobedded Systems GmbH, Gladbeck, Germany), as recommended by Leitner et al. [13]. Surface electromyography (EMG) of the PFM was transmitted through telemetry and recorded with a 16-channel telemetric system (TeleMyo 2400 G2, Noraxon USA Inc., Scottsdale, AZ). A reference electrode (Ambu Blue Sensor N, Ballerup, Denmark) was placed on the right anterior superior iliac spine. The vertical GRF, from which the initial contacts were identified, was measured by one (DL) or two (MT) force plates (Type 9286BA, Kistler Instrument AG, Winterthur, Switzerland). The participants wore standardised running shoes (Adidas Duramo 6). The drop landing exercise was conducted from three stairs at heights of 15, 30 and 45 cm (DL 15, 30, 45). A mini-trampoline with a 1.12-m diameter ("bellicon® classic", bellicon Schweiz AG, Switzerland) was used for the MT exercise. According to the manufacturer's guidelines, the trampoline stiffness was adjusted with blue rope rings for participants of up to 60 kg bodyweight and with yellow rope rings for those up to 90 kg. The Coconut Metronome app (nuit software, version 1.0.1 for iOS7) was used to produce a jump frequency of moderate [90 beats per minute (bpm): MT 90] and high (75 bpm: MT 75) jumping on the mini-trampoline.

Procedure

Informed consent and Tegner Activity Scale (TAS) were obtained prior to determination of demographic characteristics. In case of a negative pregnancy test, participants were instructed on how to contract the PFMs voluntarily. Vaginal palpation was performed in supine position and graded by a

Table 1 Labels and descriptions of applied variables related to activity and time intervals (in accordance with [13, 14, 20])

Variable	Description
T–30–0	Pre-activity within 30 ms before foot strike, %MVC
T0	Foot strike
T0–30	30 ms latency response after foot strike, %MVC
T30–60	30–60 ms after foot strike: short latency monosynaptic response in the spinal cord, %MVC
T60–90	60–90 ms after foot strike: mid-latency oligosynaptic response in the spinal cord, %MVC
T90–120	90–120 ms after foot strike: long latency oligosynaptic response in corticospinal areas, %MVC
T120–150	120–150 ms after foot strike: long latency succeeding response, %MVC
EMGpeak	Peak PFM activity, %MVC
tEMGpeak	Time between T0 (foot strike) and peak activity, ms

trained investigator according to the modified Oxford grading system [18]. The participants inserted their vaginal probe, and the investigator checked the correct position. The wires of the vaginal probe were connected to the EMG amplifier, and the reference electrode was attached. The electrode impedance was checked with an impedance metre (Model D175, Digitimer Ltd., Welwyn Garden City, UK) and was ≤ 2 kΩ in all cases. In standing position, the PFM activity at rest was recorded during 30 s, followed by two 5 s maximum voluntary contractions (MVC) with a break of 15 s in between. The five DLs with both feet on the force plate started from a height of 15 cm, followed by 30 cm and 45 cm with only as much knee bending as necessary. MT 90, 75 was performed and measured PFM involuntary activity for 20 s. For the analysis, ten MT jumps (numbers 11 to 20) were selected.

Data processing

Electromyography data of the PFM activity were amplified with a gain of 1000 and sampled at a rate of 3 kHz using a 16-bit analog-to-digital converter (Type National Instruments® PCIe 6321, National Instruments®, Austin, TX, USA) and the software package "Analoge und Digitale Signalverarbeitung" (ADS), version 1.12 (uk-labs, Kempen, Germany). The bipolar raw EMG signals of the PFM were first digitally band-pass filtered with 20 to 500 Hz (Butterworth filter, 24 db/octave filter steepness, zero phase). MVC activity was smoothed with 200-ms moving root-mean square windows.

EMG signals were parametrized by calculating root mean square (RMS) values within specific time intervals (see Table 1). The mean of peak activities during two MVCs in standing position was set as 100%. All EMG outcome variables were normalized to MVC peak activity (in %MVC). The PFM activity onset threshold was calculated by the mean rest tone plus 2 standard deviations and normalized [19]. According to former study protocols [13, 14, 20], time intervals and variables were applied (Table 1). MATLAB (version 2016b, The Mathworks Inc., Natick, USA) was used to check the plausibility of the data visually, to process EMG signals (filtering, parametrization) and to detect initial contacts of the vertical GRFs.

Statistics

Statistical analyzes were conducted using SPSS (version 24.0, SPSS Inc., Chicago, IL). All variables were tested for normal distribution by the Shapiro-Wilk test. Non-parametric tests

Table 2 Descriptive statistics of the results: median (25th and 75th percentile) of drop landings (DLs) of 15, 30 and 45 cm and mini-trampolining (MT) with 90 and 75 beats per minute; variables as explained in Table 1

Jumps → Variables ↓	DL 15 Median (25th P; 75th P)	DL 30 Median (25th P; 75th P)	DL 45 Median (25th P; 75th P)	MT 90 Median (25th P; 75th P)	MT 75 Median (25th P; 75th P)
T–30–0 (%MVC)	74.7 (49.6; 96.5)	95.1 (65.9; 110.8)	103.8 (77; 120,5)	42.8 (32.4; 66.9)	56.5 (45.2; 65.5)
T0–30 (%MVC)	82.5 (60.3; 100,6)	99.0 (76.5; 140.9)	121.6 (71.7; 165.7)	48.1 (36.5; 72.6)	62.9 (50.4; 81.2)
T30–60 (%MVC)	76.2 (49.8; 102.8)	97.4 (69.4; 143.4)	109.5 (77; 183.3)	56.1 (40.5; 66.2)	70.7 (51.7; 89)
T60–90 (%MVC)	65.4 (40.7; 97.7)	70.4 (46; 147.7)	98.1 (66.6; 163.2)	52.6 (43; 80.5)	65.6 (56.8; 81.8)
T90–120 (%MVC)	51.8 (32.9; 76.9)	62.5 (42; 104.6)	66.1 (46; 150.2)	51.1 (39.2; 76.7)	63.6 (52.9; 82.7)
T120–150 (%MVC)	36.2 (32.9; 75.5)	55.1 (38; 97.3)	62.3 (44.4; 120.5)	52.0 (38.9; 73.6)	69.8 (50.8; 82.6)
EMGpeak (%MVC)	114.5 (80.6; 162.2)	143.2 (102.2; 255.1)	181.6 (110.4; 259.9)	85.3 (62.9; 131.3)	117.6 (98; 177.9)
tEMGpeak (ms)	41.0 (26.1; 63)	33.6 (28.1; 53.3)	43.8 (26.5; 66)	133.3 (99.5; 147.1)	132.8 (96; 189.8)

Table 3 Variables as explained in Table 1; values of Friedman and post hoc Wilcoxon paired test of drop landings (DLs) from 15, 30 and 45 cm; values of Wilcoxon paired test of mini-trampolining (MT) with 90 bpm and 75 bpm

Variables	DL				MT
	Friedman	Post hoc Wilcoxon 15/30	Post hoc Wilcoxon 15/45	Post hoc Wilcoxon 30/45	Wilcoxon 75/90
T–30–0 (%MVC)	< 0.001	0.004	0.001	0.017	0.001
T0–30 (%MVC)	< 0.001	0.007	0.002	0.020	0.002
T30–60 (%MVC)	0.002	0.004	0.002	0.011	< 0.001
T60–90 (%MVC)	< 0.001	0.008	0.001	0.023	0.002
T90–120 (%MVC)	0.002	0.013	0.001	0.109	0.003
T120–150 (%MVC)	0.001	0.007	0.002	0.007	0.004
EMGpeak (%MVC)	< 0.001	0.002	0.001	0.063	0.001
tEMGpeak (ms)	0.305	0.679	0.539	0.535	0.501

were conducted, as 45% of the variables were not normally distributed. First, Wilcoxon tests checked whether PFM activity was higher than the onset threshold. Subsequently, Friedman tests examined the differences between DL 15, 30 and 45 during all time intervals ($p > 0.05$), and post hoc Wilcoxon tests were conducted to elucidate the significant pairs. MT 90 and 75 were tested by Wilcoxon tests ($p > 0.05$). To obtain an overview of the PFM reflex and involuntary activity and the provoked GRF, graphics were created in Excel (Figs. 2 and 3).

Results

Seventeen healthy, continent and nulliparous women were recruited. One was not able to perform a voluntary PFM contraction, and therefore it was not possible to assign the strength according to modified Oxford Scale. Sixteen women met the inclusion criteria and participated in the study. The average height was 1.67 ± 0.07 m and bodyweight 61.8 ± 7.2 kg. The body mass index (BMI) was 22.3 ± 2.4 kg/m^2, and the median strength of the PFMs according to the Oxford Scale was 4.0

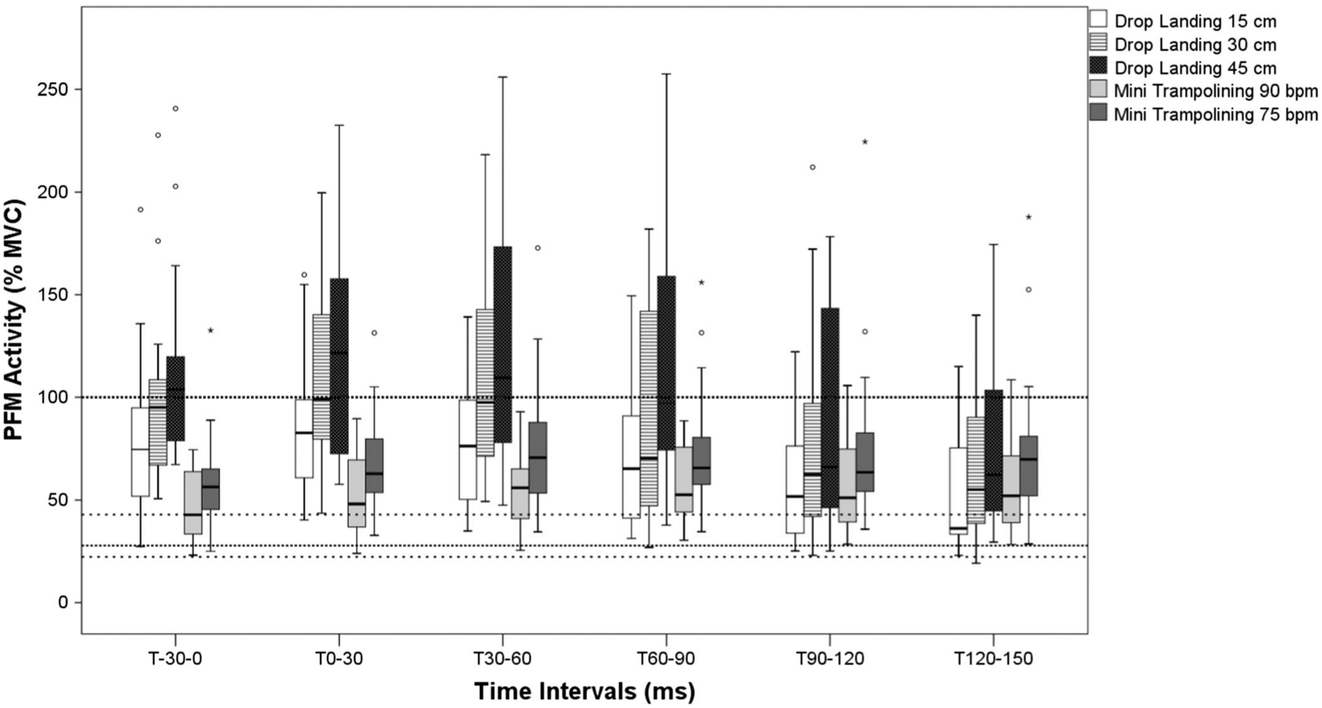

Fig. 1 PMF activity clustered to time intervals as explained in Table 1: median; 25th and 75th percentile; MVC: maximal voluntary contraction; %MVC: percent of activity related to maximal voluntary contraction. Onset: median onset activity of PFM = 27.8 (25th and 75th percentile 22.3 %MVC, 42.9 %MVC); drop landings from 15 to 45 cm; mini-trampolining 90 and 75 bpm (beats per minute)

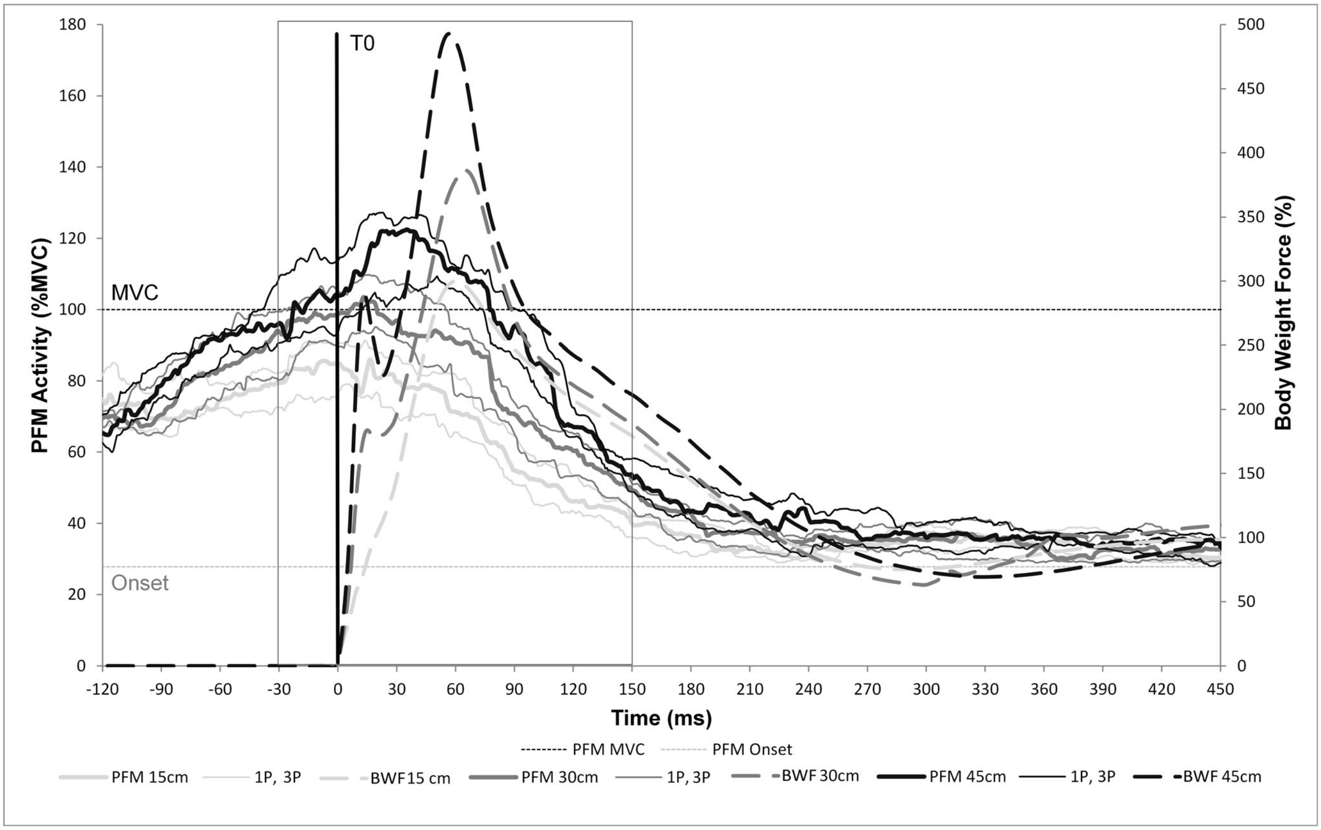

Fig. 2 Drop landings (DLs) from heights of 15, 30 and 45 cm (15, 30, 45): PFM activity during time − 120 to 450 ms related to T0 (foot strike); grey frame: pre- and reflex activity − 30 to 150 ms; %MVC: percent of activity related to peak activity during maximal voluntary contraction; light grey lines DL 15; dark grey lines DL 30; black lines DL 45; wide lines PFM median activity, narrow lines 25th and 75th percentile; body weight force (BWF%): ground reaction force (GRF in Newton) related to bodyweight (in kg); dotted light grey lines: BWF DL 15; dotted dark grey lines BWF DL 30; dotted black lines BWF DL 45; small dotted light grey line = onset: median PFM onset threshold 27.8%; small dotted black line = MVC: maximal voluntary contraction 100%

(25th and 75th percentiles: 4.0, 5.0). The Likert-scaled Tegner Activity Scale (TAS; range, 0–10) was used to obtain an overview of physical condition and showed a median score of 4.0 (25th and 75th percentiles: 4.0, 5.8). Descriptive statistics are presented in Table 2. The onset threshold was calculated as 27.8 %MVC and ranged from 22.3 to 42.9 %MVC (25th and 75th percentile). For all DLs and MTs and during all time intervals, the PFM activity was significantly higher than the onset threshold ($p < 0.05$).

The EMG pre-activity and reflex activity increased significantly with growing DL heights and on the MT with slower jumping frequency ($p < 0.05$) (Table 3). The only exceptions with no statistical significance were DL 30 as well as the maximal EMG value (EMGpeak) DL 45 in the T90–120-ms time interval. Figure 1 gives an overview of PMF activity during the applied time intervals.

DL triggered a pre-activity that with 75–104% MVC was nearly twice as high as on MT (43–56% MVC). DL reached their peak reflex activity (EMGpeak 115–182% MVC) during the first 34–44 ms (tEMGpeak) and declined nearly to the onset threshold within 180 ms (Fig. 2). In contrast, on MT 90 and 75 the peak reflex activity (EMGpeak) was reached at 133 ms after foot strike, with an intensity of 85% MVC (MT 90) to 118% MVC (MT 75), and lasted 450 ms until the PFMs returned nearly to the onset threshold (Fig. 3).

The BWF during DL increased within the first 60–70 ms to the peak, whereas on the MT the BWF reached the peak between 180 and 210 ms (Figs. 2 and 3).

Discussion

This study confirmed existing reflexive PFM activity during impact exercises such as drop landing from 15, 30 and 45 cm as well as mini-trampolining with 90 and 75 jumps per minute in healthy young women. In addition, the reflexive PFM activity may be observed considering the existing BWF.

As it was hypothesized, for DL 15, 30 and 45 as well as MT 90 and 75 and for all time intervals, the PFM activity exceeds the onset threshold. This is comparable

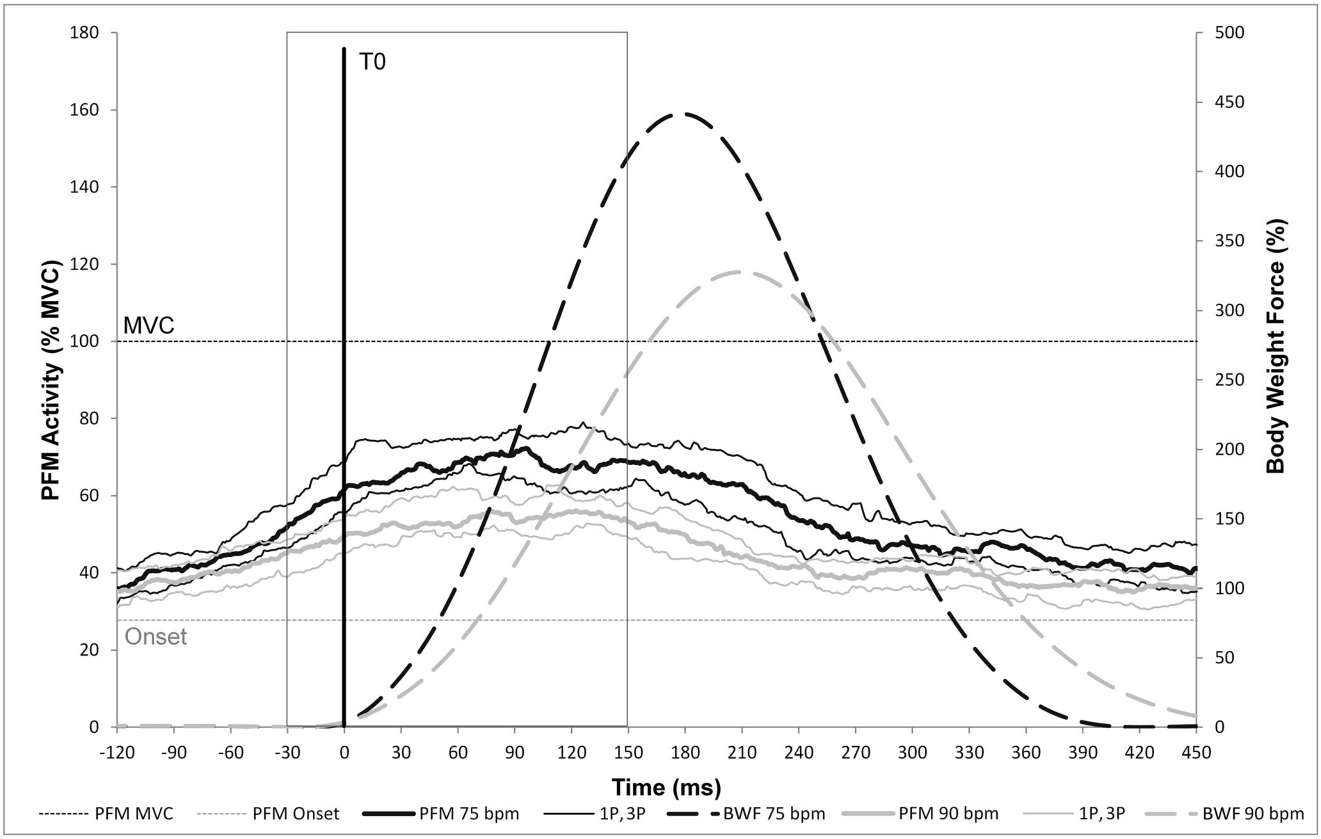

Fig. 3 Mini-trampolining (MT) with 90 + 75 (90, 75) beats per minute (bpm): PFM activity during time − 120 to 450 ms related to T0 (foot strike); grey frame: pre- and reflex activity −30 to 150 ms; %MVC: percent of activity related to peak activity during maximal voluntary contraction; light grey lines MT 90; black lines MT 75; wide lines PFM median activity, narrow lines 25th and 75th percentile; body weight force (BWF %): ground reaction force (GRF in Newton) related to bodyweight (in kg); dotted light grey lines: BWF MT90; dotted black lines BWF MT 75; small dotted light grey line = onset: median PFM onset threshold 27.8%; small dotted black line = MVC: maximal voluntary contraction 100%

to the findings of Leitner et al. [13] and Luginbuehl et al. [14], who showed higher PFM activity during running than during standing. With 28 %MVC, the median onset threshold of this investigation was below the results of Leitner et al. [13], who had mean values from 41 for the continent group and 37 %MVC for the incontinent group. This investigation is in line with the study protocol of Luginbuehl et al. [19], which indicates that it could be important to implement high-impact whole-body exercises to maintain good PFM function.

Furthermore, the second hypothesis regarding a heightening of PFM activity by increasing jumping height was confirmed. This can be explained by rising BWF, which was produced by higher DL as well as by higher jumping on the MT [13, 21]. This phenomenon was also discovered by Fleischmann et al. in their investigation of the effect of lateral jumps on lower limb muscles [22]. Fast rising of the BWF during the first 60–70 ms after foot strike, as occurred during DLs, produced the highest mean PFM activities in time interval T0–30 (82–122 %MVC) and lasted only 180 ms until the onset threshold was nearly reached. This is similar to Luginbuehl et al. [14], who also showed the highest mean PFM activity (82–98 %MVC) during running in the same time interval, but different from Leitner et al. [13], who had the highest mean PFM activities during pre-activity (T-30-0). It is assumed that pre-activity and monosynaptic reflexes on the level of the spinal cord took place [20].

On the other hand, slow rising of the BWF for 180–210 ms after foot strike, as occurred during MT, produced a peak reflex PFM activity, which was reached in time interval T30–60 with an intensity of only about 50–70% MVC but lasted two to three times longer (until 450 ms) than during DL until the onset threshold was nearly reached. This finding suggests that monosynaptic as well as oligosynaptic responses in the spinal cord and corticospinal areas [20] occurred under the damped landing condition on the MT.

Comparing the DL and MT, similar PFM peak EMG (EMGpeak) activities (115–118 %MVC) were reached with DL 15 and MT 75 (Table 3). The median in DL 15 (83 %MVC) was higher than TR 75 (71 %MVC), although the

BWF was 150% lower for DL15 than MT 75. However, MT 75 produced PFM activity that was up to twice as long (up to 450 ms) as DL 15 (up to 210 ms) (Figs. 2 and 3).

Another result was that PFM pre-activity during running [14] as well as during DL and MT in this investigation was about 5–15% lower than the highest mean activity (T0-30). In other words, participants could anticipate how strong the impact would be and were therefore able to adapt their pre-activity of the PFM. This phenomenon was also described in investigations of limb muscles during DL [22] and lateral jumps [20].

Looking at the time to reach the peak of PFM activity, it is remarkable that for the cyclic movements during MT with 133 ms it was similar to running (104-130 ms [13]) but different from the acyclic movement of the DL (34–44 ms). This fact raises the question of whether the PFMs need more time to reach the peak activity during cyclic movements.

Comparing the two jumping styles of DL and MT, the fast increase of the GRF within DLs provokes fast peak PFM activity (34–44 ms) and high impact, whereas a slow increase of the GRF within MT provokes slow peak PFM activity (133 ms) and lower impact.

While observing the median EMG values in all time intervals, the activation pattern described by Leitner et al. [13] becomes apparent during DL with a decrease of PFM activity in the T30–60 time interval. However, PFM values on the MT decrease one time interval later (T60–90) and may be the consequence of the delayed GRF maximum due to the damping characteristics of the trampoline (Fig. 1).

Future investigations focusing on involuntary reflexive PFM training intervention should first determine the intra- and intersession reliability.

It would be interesting to compare the EMG activity of the lower limbs, near hip and deep abdominal muscles during jumps to detect whether it is similar to the PFM activation pattern. Additionally, assessing possible synergistic activity or crosstalk during complex functional movements would also be of interest.

More research is required to obtain a deeper insight into PFM activity patterns of women affected by SUI or postmenopausal women during high-impact sports, such as DL and MT, as well as during running.

Limitations

Crosstalk may affect the validity of EMG data [23]. The recently published scoping review by Flury et al. [24] about crosstalk on vaginal EMG mentioned that there is no general rule about which muscles' crosstalk to the PMF is expected. Several muscles may come into question: the obturator internus, hip adductors, gluteals, rectus femoris, medial hamstrings and deep abdominal muscles. In addition, they determined that crosstalk may also be interpreted as synergistic activation of neighbouring muscles, which is necessary to assist stabilisation of the pelvic girdle. As recommended by other researchers [13, 25], the tripolar vaginal probe, which was used in this investigation, is the best possible option to decrease the chance of recording crosstalk.

PFMs have a great impact on the elevation of the bladder neck. It is also confirmed that voluntarily activated PFMs, which are strongly supported by abdominal muscles (AM), may result in a subsidence and opening of the bladder neck in a funnel shape because of an increase of intraabdominal pressure (IAP) [26]. To date, there are no data on the interconnection among the PFMs, AM and IAP during jumping exercises.

Additionally, no studies regarding lower limb EMG activity during MT could be found. However, a comparison of PFM activity with the activity of lower limb muscles would have been interesting to confirm the PFM activation pattern on the MT.

As this investigation, which included 16 young and healthy participants with strong PFMs, was conducted in an exploratory manner, the question of transferability is raised regarding women with weak or normal PFMs, women who are affected by SUI and women after birth.

Conclusion

This study makes a contribution to confirming that PFMs are involuntarily and reflexively activated during complex functional movement. DL and MT require muscle strength from the whole body and also provoke reflexive PFM activity. To date, the effect of impact training on weak or normal PFMs is still unknown.

Further research on PFM function triggered by training of complex functional movements such as running or jumping would be of great interest.

Compliance with ethical standards

Conflicts of interest None.

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