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Does a not-so-recent ankle sprain influence interjoint coordination during walking?

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ABSTRACT

Background: Ankle sprains are common joint injuries in daily and sports activities, whose underlying mechanisms have been amply studied. If joint structures are directly damaged, neuromuscular activity can be affected, particularly in the time domain.

This study aims to establish whether previous ankle injury correlates with changes in the inter-joint synergy of the entire lower limb and in the muscle activity pattern during walking.

Methods: Three-dimensional walking-gait analysis was conducted on twenty-four adults. Ten of them had never suffered from ankle sprain; fourteen had suffered from ankle sprain at least once during the three preceding years.

Continuous Relative Phase (CRP) between the moving limbs assessed inter-joint coordination, and muscular activity was recorded by EMG.

Findings: CRP between ankle and knee and between ankle and hip indicates that both joints moved in tight synchronization in the same direction on the injured side, whereas there was a time lag between joints on the healthy side for each sprained participants or on both side for the control group.

Start-time and/or duration of muscular activity of tibialis anterior, soleus and peroneus longus occurred earlier and were longer on the injured side, respectively.

Interpretation: Our findings suggest that ankle sprain modifies inter-joint coordination and muscular activity of the injured limb, inducing not an entirely new pattern of coordination but an alteration of the existing pattern. CRP revealed slight modifications in the extant inter-joint coordination which may not be captured by other kinematic variables, which opens perspectives on therapy and relapse prevention.

1. Introduction

Ankle sprains are most common injuries in daily-life activities and in sports (Fong et al., 2007; Lambers et al., 2012). The mechanism leading to such injuries is well known (Chu et al., 2010) and has been the object of numerous studies, particularly in the view of rehabilitation (Chan et al., 2010; Kemler et al., 2011). A majority of such studies highlights that recovery of all functional and kinematic aspects of movement is essential to avoid functional instability, indeed an important factor for possible relapse (Kerkhoffs et al., 2012).

Beyond the articular structures of the injured joint, the afferent and efferent systems are also affected. The neural tissue about the ankle sprain is also impacted, leading to an alteration of distal joints such as the knee (Pahor and Toppenberg, 1996). This alteration is mostly expressed in the time domain. During an ankle sprain, the knee flexion is initially delayed during the swing phase, but this delay is then compensated immediately before initial contact, allowing for a fully extended knee (Gehring et al., 2013). Moreover, basketball players with multiple previous ankle sprains present increased ankle repositioning errors and postural sway during stance, which corroborates the assumption that proprioceptive afferents are impacted by a sprain (Fu and Hui-Chan, 2005). Thus, when joint structures are directly damaged and exhibit biomechanical abnormalities, the neuromuscular system can also be affected, leading to a modification in the overall kinematics of the limb in a large variety of tasks (Hunt, 2003).

Alterations of the afferent neural stream associated with previous ankle sprain influence motor planning and the activation patterns of the muscles involved in mobilizing the joint (Bullock-Saxton et al., 1994).

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These changes may be viewed as modifications of the synergy that brings together the components in order to produce a specific coordinated motor output (Latash, 2008). A synergy spans several joints, harnessing numerous degrees of freedom in order to achieve the same goal (St-Onge and Feldman, 2003). A notable instance of synergy is the ankle-knee coordination involved in leg motion (Dedieu and Zanone, 2013; Hwang and Abraham, 2001a, 2001b). In an exploratory study, Castro et al. (2009) indicated that the coupling between the ankle and the knee of athletes who had suffered an ankle sprain is tighter during a unipodal jump, as compared to healthy athletes. The latter move their ankle and knee joints with a notable temporal shift, so that the shock due to the foot landing can be absorbed efficiently, a mechanism absent in sprained limbs. Finally, the interlimb symmetry is affected during a drop vertical jump in subjects with acute lateral ankle sprain relative to controls (Doherty et al., 2014).

Structural consequences of ankle sprain set aside, the issue arises as to how the different joints adapt to this deleterious state in order to produce an adequate movement. In this juncture, a dynamic pattern approach to coordination offers tools to identify and capture how the various joints involved are coupled within a synergy (Kelso, 1995; Schöner and Kelso, 1988). More specifically, the relative phase (Φ) proved to characterize truthfully and measure accurately the actual coordination between two limb segments moving periodically (Haken et al., 1985; Jeka and Kelso, 1989). In line with a coupled oscillators theory (*e.g.*, Schwemmer and Lewis, 2011), only two values of relative phase between the oscillating segments can be performed spontaneously: 0°, corresponding to both limbs moving in-phase, and 180° when they move in anti-phase (Haken et al., 1985; Kelso and Jeka, 1992). A positive relative phase value indicates that the distal segment is ahead of the proximal one, that is, the former is more advanced in the completion of its motion cycle than the latter, and inversely. Moreover, relative phase variability, typically assessed by the standard deviation of Φ, provides a measure of the stability of the coordination between the two interacting limbs (Hamill et al., 1999; Stergiou et al., 2001; van Emmerik and Wagenaar, 1996).

Both the average value and the variability of relative phase are affected by the existing coupling between the moving limbs, following two simple rules. On the one hand, the coupling increases their synchronization: The stronger the coupling, the closer to 0° or 180° the relative phase. On the other hand, the coupling increases the pattern stability: The stronger the coupling, the lower the relative phase variability, hence the higher the stability of the coordination (Jeka and Kelso, 1989).

A parameter that modifies the coupling between the limbs is muscle stiffness, which evolves relative to the motion of the Center of Mass (CoM) during the single support phase (Kim and Park, 2011). Lower limb stores more elastic energy, which contributes to body balance during single-leg stance and to propulsive energy during push-off. The increase in whole-leg stiffness is related to an increase in the tension of the knee and ankle joints muscles (Bovi et al., 2011). As a first result, a strong inter-joint coupling leads to a relative phase close to in-phase, indicating a synchronous movement in the same direction of two coordinated limbs (Dedieu and Zanone, 2013; Seay et al., 2006). As a second result, a strong coupling damps the perturbations affecting each limb, thereby reducing interlimb variability. Thus, relative phase captures lower limb stiffness, which is a mechanism underlying interlimb synchronization and stability.

The aim of the present study is to establish how previous ankle injury may affect the coordination of the entire lower limb during walking, that is, whether it induces changes in the inter-joint synergy and in the muscle activity pattern. Thus, the synchronization between the ankle, the knee and the hip assessed by their relative phase will be analyzed in the sagittal plane during walking along with the associated pattern of muscular activity, as captured by ElectroMyoGraphy (EMG), for participants who have or have not suffered an ankle sprain fairly recently. This procedure may shed a light onto how the motor command issued by the Central Nervous System (CNS) to the muscles could adapt following a previous ankle sprain, thereby altering the ensuing interjoint coordination (Hamill, Haddad, & McDermott, 2000; Hamill et al., 1999; Kelso, 1984).

2. Methods

This study was conducted in accordance with the Helsinki Declaration and has been approved by the local ethics committee.

2.1. Participants

Twenty-four adults (males; age: 21.59 (SD 1.88) years; weight: 80.13 (SD 7.32) kg; height: 177.54 (SD 4.77) cm) volunteered to participate in the study. Ten of them had no previous ankle sprain ever and composed the control group. The other fourteen participants had suffered from ankle sprain at least once during the three preceding years, but none in the last year. The ankle sprain had affected only one side and had not been treated with immobilization (Knight and Weimar, 2012).

The amount of time lapsed from the participants' last sprain was 21.4 month (SD = 7.6). All participants qualified to be free of any type of pain and of any orthopedic or neurological problem in the lower extremities at the date of the experiment. No participant was engaged in physical activity.

Since no difference was found after measurement and comparison between a subgroup with a history of multiple ankle sprains and a subgroup with a history of single sprain (Table 1), the two subgroups were merged into a single study group with a history of ankle sprain (Sprained Group) to be contrasted with a control group without any sprain (Healthy Group).

All participants exhibited a low instability in both ankles, whether these had been injured or not, as measured by the Cumberland Ankle

Table 1
Gait parameters, mean joint angles and Range of Motion mean values (SD). N is the number of participants and n is the number of studied ankles.

	Between groups		Within sprained group	
	Healthy group	Sprained group	History of multiple ankle sprains	History of single sprain
	(N = 10; n = 20)	(N = 14; n = 14)	(N = 5; n = 5)	(N = 9; n = 9)
Stance phase ratio (SD) (%)	59.1 (1.2)	60.2 (1.4)	60.16 (1.25)	60.22 (1.48)
Heel stance phase (SD) (%)	26.5 (2.4)	25.1 (1.6)	24.88 (1.44)	25.18 (1.83)
Ankle mean angle (SD) (°)	− 0.12 (0.34)	− 0.19 (0.40)	− 0.14 (0.44)	− 0.22 (0.40)
Knee mean angle (SD) (°)	0.32 (0.33)	0.27 (0.34)	0.27 (0.25)	0.27 (0.39)
Hip mean angle (SD) (°)	0.29 (0.52)	0.23 (0.57)	0.1 (0.54)	0.31 (0.61)
Ankle ROM (SD) (°)[a]	1.55 (0.06)	1.33 (0.17)	1.28 (0.18)	1.36 (0.16)
Knee ROM (SD) (°)	1.04 (0.07)	1.06 (0.01)	1.06 (0.02)	1.05 (0.01)
Hip ROM (SD) (°)	1.46 (0.09)	1.57 (0.22)	1.56 (0.11)	1.58 (0.24)

[a] Denotes a significant difference (P < 0.05) for the Between Groups/Within Sprained Group comparison.

Instability Tool (Hiller et al., 2006).

2.2. Procedure

Participants were asked by the experimenter to initiate walking barefoot at a spontaneous speed back and forth in a Gait Analysis Room (10 m × 4.5 m). Spontaneous speed was chosen to avoid any gait modifications due to speed constraint (Plotnik et al., 2013). One minute or so after walking onset, recording started while participants were walking in a straight line. Therefrom, five successive gait cycles were extracted and included in the analyses.

Each participant performs one single trial.

2.3. Data collection

The 3D coordinates of reflective markers placed on body landmarks according to the Plug-in-Gait Marker Placement were recorded at 100 Hz using a six-camera Vicon system (Oxford Metrics Ltd., Oxford, England).

Muscular activity was recorded through a surface EMG system (Trigno™ Wireless System, Delsys, Boston, MA). Following an appropriate skin preparation (Hermens et al., 2000), electrodes were placed on both sides over the bellies of *tibialis anterior*, *soleus*, *gastrocnemius medialis*, *gastrocnemius lateralis*, *peroneus longus*, *rectus femoris* and the *long head of biceps femoris* in accordance with SENIAM recommendations for sensor locations.

2.4. Data processing

The raw 3D coordinates were smoothed through a two-way Butterworth low-pass filter with a cutoff at 6 Hz.

The gait cycle duration was calculated as the time between two successive contacts of the same foot determined by a foot switch fixed on the plantar face of the heel, the first and the fifth metatarsal heads. The average ratio between the stance duration and the gait cycle duration was then computed for each gait cycle and was expressed as a percentage of the total cycle duration.

From the 3D coordinates, the kinematic data of the ankle, knee and hip were calculated, spatially normalized within the range of -1 to1 (Hamill et al., 1999) and the time normalized, so that each gait cycle lasted 100 samples (Kurz and Stergiou, 2002).

The relative phase value Φ was computed by a Continuous Relative Phase (CRP) algorithm, using a Hilbert transform within the range of $-180^\circ < \text{CRP} \le 180^\circ$ (Pikovsky et al., 2001).

The EMG signal was band-pass filtered between 10 and 400 Hz. The linear envelope was obtained by low-pass filtering of the rectified signals at 6 Hz (Winter, 2009). Each linear envelope was normalized in time over 100 samples and in magnitude in reference to the highest peak of each gait cycle. A muscle was considered to be active when the signal magnitude was higher than the magnitude of two standard deviations computed during relaxed upright standing (Chang et al., 2007). The start and duration of muscle activity were expressed as a percentage of the gait cycle.

2.5. Statistical analysis

Data were compared intra-subject (ankles of the injured *vs.* healthy side) as well as inter-subjects (participants with *vs.* without previous ankle sprain) (Vaes et al., 2002).

The temporal similarity of joint angular displacement was measured by a Pearson product-moment correlation (Derrick et al., 1994) for each participant. The mean values for gait cycle were averaged and analyzed through a one-way ANOVA (with *vs.* without previous ankle sprain).

The mean values for the start and duration of muscle activity were compared intra-subject (injured *vs.* healthy side) and inter-subjects (with *vs.* without previous ankle sprain) through a one-way ANOVA.

The significance level was set at $P < 0.05$.

Table 2
Anthropometric and BMI mean values (SD).*

	Healthy group (N = 10)	Sprained group (N = 14)
Height (SD) (cm)	178.2 (5.7)	176.8 (4.8)
Weight (SD) (kg)	82.4 (7.9)	77.9 (7.4)
Age (SD) (year)	21.2 (2.3)	21.9 (1.8)
BMI (SD)	24.9 (1.9)	25.9 (1.8)

* Denotes a significant difference ($P < 0.05$).

3. Results

3.1. Individual anthropometrical parameters (Table 2)

The individual data did not show any significant difference between participants with or without previous ankle sprain.

3.2. Passive Range of Motion (Table 3)

Passive Range of Motion of ankle, knee and hip did not differ between Healthy and Sprained group and, within Sprained Group, between participants presenting multiple ankle sprain history and single sprain history.

3.3. Score obtained in the Cumberland Ankle Instability Tool

The score obtained in the Cumberland Ankle Instability Tool for the two ankles whether injured or not did not show any significant difference between participants with or without previous ankle sprain (M = 24.8, SD = 1.9 and M = 25.7, SD = 1.3), respectively ($P = 0.10$).

3.4. Gait parameters and mean joint angle (Table 4 and Fig. 1)

The ratio of stance phase was not significantly different between participants with or without previous ankle sprain while walking, either over the entire stance phase ($P = 0.17$) or from the initial contact to the mid-stance (heel stance phase) ($P = 0.25$).

The results did not indicate significant differences in the mean angle of the ankle, the knee or the hip between the two groups. Variability

Table 3
Passive Range of Motion mean values (SD). N is the number of participants and n is the number of ankles/samples.*

	Between groups		Within sprained group	
	Healthy group	Sprained group	History of multiple ankle sprains	History of single sprain
	(N = 10; n = 20)	(N = 14; n = 14)	(N = 5; n = 5)	(N = 9; n = 9)
Passive Ankle ROM (SD) (°) *knee flexed*	1.78 (0.13)	1.71 (0.18)	1.68 (0.15)	1.72 (0.20)
Passive Ankle ROM (SD) (°) *knee extented*	1.64 (0.18)	1.57 (0.17)	1.44 (0.13)	1.62 (0.16)
Passive Knee ROM (SD) (°)	1.26 (0.09)	1.3 (0.02)	1.29 (0.01)	1.31 (0.02)
Passive Hip ROM (SD) (°)	1.73 (0.07)	1.61 (016)	1.61 (0.01)	1.61 (0.19)

* Denotes a significant difference ($P < 0.05$) for the Between Groups/Within Sprained Group comparison.

Table 4
Gait parameters, mean joint angles and Range of Motion mean values (SD). N is the number of participants and n is the number of ankles/samples.

	Between groups		Within sprained group	
	Healthy group	Sprained group	History of multiple ankle sprains	History of single sprain
	(N = 10; n = 20)	(N = 14; n = 14)	(N = 5; n = 5)	(N = 9; n = 9)
Stance phase ratio (SD) (%)	59.1 (1.2)	60.2 (1.4)	60.16 (1.25)	60.22 (1.48)
Heel stance phase (SD) (%)	26.5 (2.4)	25.1 (1.6)	24.88 (1.44)	25.18 (1.83)
Ankle mean angle (SD) (°)	− 0.12 (0.34)	− 0.19 (0.40)	− 0.14 (0.44)	− 0.22 (0.40)
Knee mean angle (SD) (°)	0.32 (0.33)	0.27 (0.34)	0.27 (0.25)	0.27 (0.39)
Hip mean angle (SD) (°)	0.29 (0.52)	0.23 (0.57)	0.1 (0.54)	0.31 (0.61)
Ankle ROM (SD) (°)*	1.55 (0.06)	1.33 (0.17)	1.28 (0.18)	1.36 (0.16)
Knee ROM (SD) (°)	1.04 (0.07)	1.06 (0.01)	1.06 (0.02)	1.05 (0.01)
Hip ROM (SD) (°)	1.46 (0.09)	1.57 (0.22)	1.56 (0.11)	1.58 (0.24)

* Denotes a significant difference ($P < 0.05$) for the Between Groups/Within Sprained Group comparison.

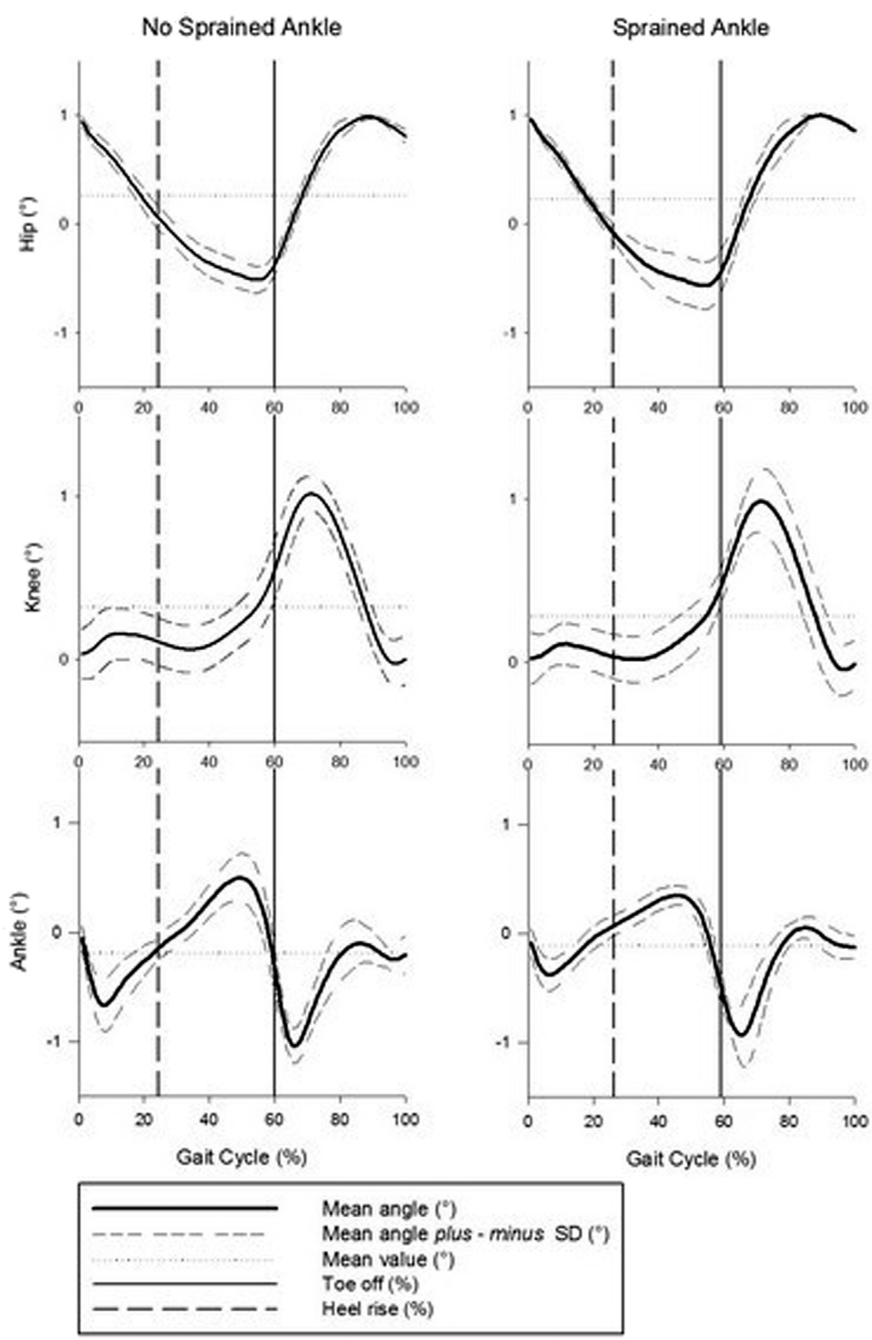

Fig. 1. Evolution of mean joint angle (°) (solid line) and SD (dashed line) of ankle (lower panel), knee (median panel) and hip (upper panel) along a gait cycle for No sprained (left plot) and Sprained ankle (right plot). Horizontal dotted line represents overall average of joint angle.

Table 5
Continuous Relative Phase mean values (SD). N is the number of participants and n is the number of ankles/samples.

	Healthy group (N = 10; n = 20)	Sprained group (N = 14; n = 14)
Ankle-knee CRP (SD) (°)*	5.50 (16.27)	0.49 (7.85)
Ankle-hip CRP (SD) (°)*	10.54 (18.52)	6.70 (13.55)
Knee-hip CRP (SD) (°)	4.74 (29.31)	9.85 (23.79)

* Denotes a significant difference ($P < 0.05$).

was not significantly different either.

However, the range of motion of the ankle in the sagittal plane was significantly lower with previous injury, between groups and within an individual (resp. P = 0.03 and P = 0.04). The range of motion of the knee and the hip was not significantly different (resp. P = 0.27 and P = 0.30).

3.5. Continuous Relative Phase (CRP) (Table 5 and Fig. 2)

Over the entire gait cycle, mean CRP between ankle and knee and between ankle and hip was significantly different between an injured ankle and a healthy ankle for each sprained subject, as well as between a sprained ankle and both healthy ankles of the control group. CRP was more in-phase on the injured side as compared to the healthy side. This means that both the ankle and knee and the ankle and hip moved tightly synchronized in the same direction in the injured side, whereas there was a lag between joints on the healthy side. The same results were found between an injured ankle and both healthy ankles of participants without previous ankle sprain. The associated standard deviation was also different in all combinations. Precisely, results indicated significant differences in mean CRP over the stance phase and no significant differences over the swing phase between sprained and non-sprained ankle (between groups and within an individual). However, mean CRP between knee and hip and the associated standard deviation between groups and within an individual are not significantly different between groups over the entire gait cycle. The same applies to the stance and swing phases.

3.6. Start and duration of muscular activity (Table 6)

Table 6 presents the average start time and duration of muscular activity during the gait cycle between groups and within an individual. Tibialis anterior was active at foot contact in both conditions between groups and within an individual. Its duration of activity was significantly longer during the stance phase while walking with previous injury between groups and within an individual for an individual (resp., 13.17% (SD: 2.22) *vs*. 11.09% (SD: 2.20); P = 0.048 and 13.17% (SD: 2.22) *vs*. 11.88% (SD: 2.26); P = 0.045). *Soleus*, was activated earlier with previous ankle sprain than without between groups and within an individual (resp., 7.39% (SD: 2.27) *vs*. 9.12% (SD: 2.33); P = 0.045 and 7.39% (SD: 2.27) *vs*. 9.48% (SD: 2.17); P = 0.032) whereas no differences were observed on start time of *gastrocnemius lateralis* and *gastrocnemius medialis*. The duration of activity of *soleus* was significantly longer with previous injury than without between groups and within an individual (resp., 44.05% (SD: 1.36) *vs*. 41.26% (SD: 0.69); P = 0.018 and 44.05% (SD: 1.36) *vs*. 41.09% (SD: 1.22); P = 0.042) whereas no differences were observed for *gastrocnemius lateralis* and *gastrocnemius medialis*. The activity of *peroneus longus* was activated earlier with previous ankle sprain than without between groups and within an individual (resp., 8.72% (SD: 2.05) *vs*. 10.79% (SD: 2.23); P = 0.033 and 8.72% (SD: 2.05) *vs*. 10.87% (SD: 1.24); P = 0.028). Moreover, its activity duration was significantly longer with previous ankle sprain than without between groups and within an individual (resp., 43.90% (SD: 2.67) *vs*. 41.87% (SD: 2.70); P = 0.021 and 43.90% (SD: 2.67) *vs*. 41.57% (SD: 3.20); P = 0.038).

4. Discussion

The present study reports significant differences in the ankle-knee synergy exhibited by the two groups of participants, with an injured *vs*. healthy ankle.

Despite the fact that variability remains roughly the same, the study shows that the mechanical linkage of the ankle and knee is weaker when the ankle has previously suffered a sprain. Yet, the relative phase indicates that ankle and knee are close to an in-phase coordination (*viz* 0° of relative phase). These findings indicate that the interjoint coordination is modified when the ankle has already suffered a sprain, but this modification does not lead to an altogether new pattern of coordination. Although the range of motion is not different, the relative phase shows a lower value, close to 0°, for the sprain group instead of 5.5° for the controls. This weakening of the linkage suggests that the system tends to take advantage of the forces generated by the stretch-shortening cycle of the muscles used in the flexion, storing more elastic energy for the propulsive phase (Joris et al., 1985; Temprado et al., 1997). Note, however, that there is no specific temporal order between the two joints. During the early phase preparing for initial contact, which is the final phase of the flight preparing for loading response, the lower limb system must absorb the associated shock (Williams et al., 2001; Williams et al., 2004). A relative phase close to 0° with a sprained ankle indicates that the coupling between the ankle and the knee was tighter. Accordingly, the range of motion of the ankle reveals that the joint is more extended just before initial contact for the ankle sprain group. The extended position and the strong coupling may contribute to rigidify the musculoskeletal system while preparing for landing and may induce an unstable position upon landing. In accordance with Wright et al. (2000), this situation is prone to increase the risk of occurrence of an ankle sprain.

During mid-stance, a difference in relative phase was also observed between groups. The ankle extension is further ahead with respect to the knee extension in the Healthy group, whereas ankle extension and knee extension are *in-phase* in the Sprain group. This synchronized movement may play a major role in stabilizing the unipodal stance phase of gait which is considered as one of the five pre-requires of a normal gait (Gage and Schwartz, 2009; Perry and Burnfield, 2010). These findings are corroborated by the muscular pattern. The muscles acting directly on the foot and ankle stability are activated earlier and their duration is longer in the Sprain Group.

In a previous study using similar tools from a dynamic approach to coordination, Donker and Beek (2002) reported loss of coordination stability in walking with an above-knee prosthesis. The asymmetry induced by using a prosthesis strongly affected the stability and the adaptability of the coordination adopted during walking. Centomo et al. (2007) showed that children with a trans-tibial amputation altered the muscle activation patterns during locomotion. This major traumatism induces radical changes in the intralimb and interlimb coordination in order to maintain an adept gait. Regarding less dramatic impairments, Leanderson et al. (1993) showed that basketball players with a previously sprained ankle demonstrated a significant increase in postural sway as compared to uninjured players. Other studies showed that disorders in the interjoint coupling were bound to generate chronic troubles affecting the range of motion (De Leo et al., 2004; Dierks and Davis, 2007; Nawoczenski et al., 1998). Stergiou et al. (1999) suggested that the lack of coordination between the subtalar and the knee joints could be responsible for various injuries related to running. They proposed that this deficit might be a good predictor of the runners' susceptibility to a future injury.

Although ankle sprain is admittedly a milder injury, our results suggest that it does modify the interjoint coordination in the injured

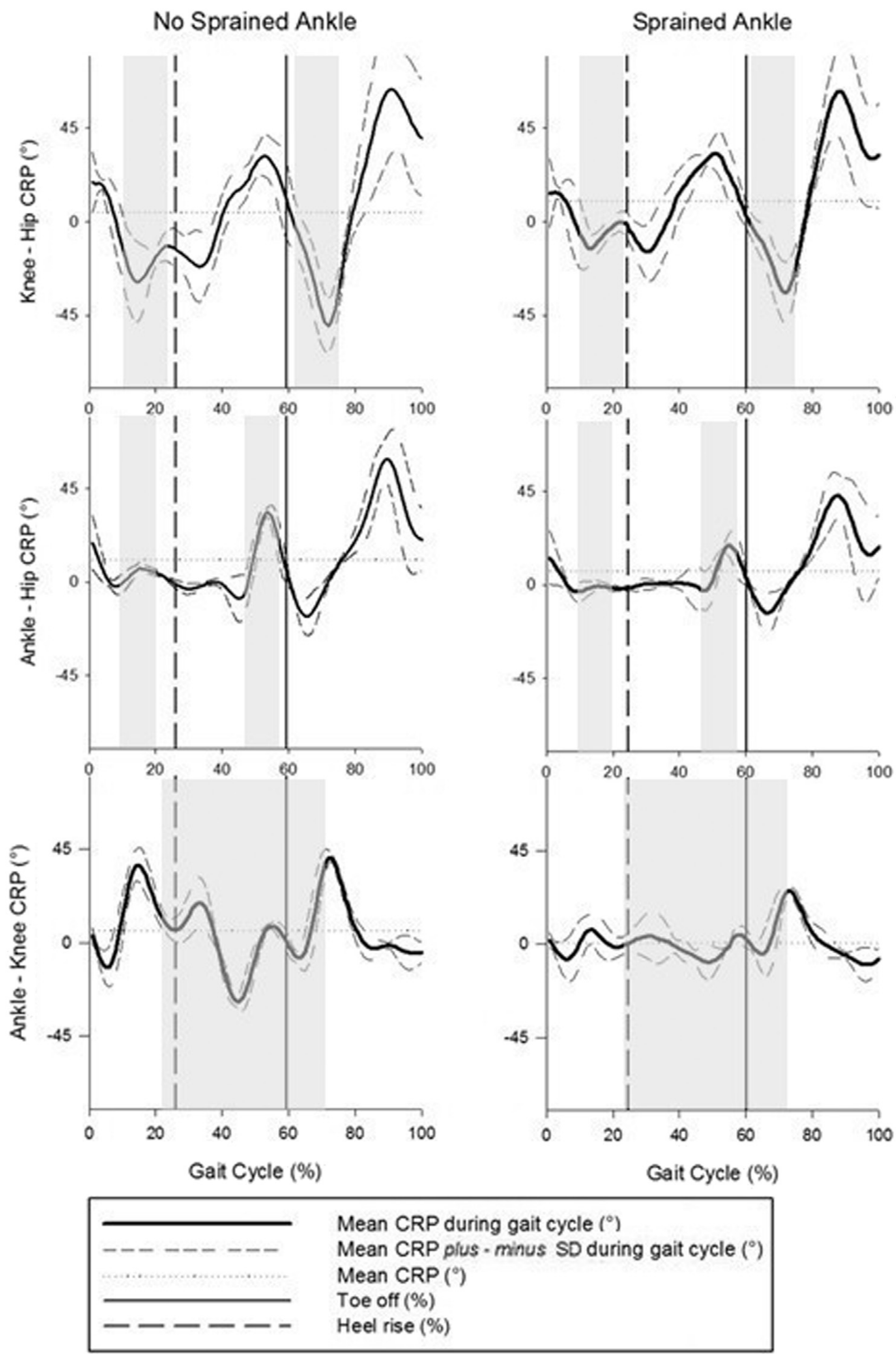

Fig. 2. Evolution of mean Continuous Relative Phase (CRP) (°) (solid line) and SD (dashed line) between ankle and knee (lower panel), ankle and hip (median panel) and knee and hip (upper panel) along a gait cycle for No sprained (left plot) and Sprained ankle (right plot). Shaded area denotes the portion of the time series that differs significantly between No sprained ankle and Sprained ankle subjects ($P < 0.05$). Horizontal dotted line represents overall average CRP.

lower limb during walking. Given that the ankle sprain occurred at least one year before the experiment and that participants did not express any pain before the experiment, the observed phenomena may pertain to the previous accident. The ankle-knee synergy shows a synchronization closer than 0° in participants who had suffered ankle sprain. The analysis of relative phase indicates that this modification does not correspond to an entirely new pattern of coordination but to an alteration of the existent pattern (Dedieu et al., 2016). These results support the idea that in the face of changing constraints, the nervous system can modify interjoint coordination while still preserving the same basic synergy (St-Onge and Feldman, 2003). Unfortunately, this modified, less synchronized and less stable coordination could represent a high-risk factor increasing the probability of accident recurrence. A tentative account for such an effect could be that ankle sprain induces traumatic lesions on the capsule and ligaments of the foot and the ankle, which may substantially disturb the information afferent from the joint (Freeman et al., 1965). Such deficient information would then impair suitable planning and execution of the motor response (Bullock-Saxton et al., 1994).

Thus, not only is relative phase a good and robust descriptor of behavioral changes in terms of transitions between coordination patterns, as shown in all previous studies on interlimb coordination, but it also provides an operational tool to reveal light modifications in an extant interjoint coordination, which may not be apparent through other variables, kinematic for instance.

Table 6
Duration and start time of muscular activity, mean values and (SD). N is the number of participants and n is the number of ankles/samples.

	Between groups		Within an individual	
	No sprained ankle	Sprained ankle	No sprained ankle	Sprained ankle
	(N = 10; n = 20)	(N = 14; n = 14)	(N = 14; n = 14)	(N = 14; n = 14)
Start time of *tibialis anterior* activity (stance phase) (SD) (%)	0 (0)	0 (0)	0 (0)	0 (0)
Duration of *tibialis anterior* activity (stance phase) (SD) (%)*/*	11.09 (2.20)	13.17 (2.22)	11.88 (2.26)	13.17 (2.22)
Start time of *soleus* activity (stance phase) (SD) (%)*/*	9.12 (2.33)	7.39 (2.27)	9.48 (2.17)	7.39 (2.27)
Duration of *soleus* activity (stance phase) (SD) (%)*/*	41.26 (0.69)	44.05 (1.36)	41.09 (1.22)	44.05 (1.36)
Start time of *gastrocnemius medialis* activity (stance phase) (SD) (%)	8.96 (2.23)	8.01 (2.25)	8.5 (2.04)	8.01 (2.25)
Duration of *gastrocnemius medialis* activity (stance phase) (SD) (%)	42.6 (2.05)	43.82 (3.27)	42.69 (2.96)	43.82 (3.27)
Start time of *gastrocnemius lateralis* activity (stance phase) (SD) (%)	8.91 (2.86)	8.3 (2.36)	8.79 (2.13)	8.3 (2.36)
Duration of *gastrocnemius lateralis* activity (stance phase) (SD) (%)	42.02 (2.62)	43.56 (2.97)	42.12 (2.42)	43.56 (2.97)
Start time of *peroneus longus* activity (stance phase) (SD) (%)*/*	10.79 (2.23)	8.72 (2.05)	10.87 (1.24)	8.72 (2.05)
Duration of *peroneus longus* activity (stance phase) (SD) (%)*/*	41.87 (2.70)	43.90 (2.67)	41.57 (3.20)	43.90 (2.67)

* Denotes a significant difference ($P < 0.05$) for the Between Groups/Within an individual comparison.

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