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Adam B. Rosen
University of Nebraska at Omaha, arosen@unomaha.edu

Nicholas T. Than
University of Nebraska at Omaha

William Z. Smith
University of Nebraska at Omaha

Jennifer M. Yentes
University of Nebraska at Omaha, jyentes@unomaha.edu

Melanie L. McGrath
University of Montana, melanie.mcgrath@umontana.edu

See next page for additional authors

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Attention is associated with postural control in those with chronic ankle instability

Adam B. Rosen,[1] Nicholas T. Than,[1] William Z. Smith,[1] Jennifer M. Yentes,[2] Melanie L. McGrath,[3] Mukul Mukherjee,[2] Sara A. Myers,[2] and Arthur C. Maerlender[4]

1 School of Health, Physical Education and Recreation, University of Nebraska at Omaha, 6001 Dodge St, HPER 207Y, Omaha, NE
2 Department of Biomechanics, University of Nebraska at Omaha, 6001 Dodge St, Omaha, NE
3 Department of Health and Human Performance, McGill 238D, University of Montana, Missoula, MT 59812
4 Center for Brain, Biology & Behavior, C89 East Stadium, University of Nebraska-Lincoln, Lincoln, NE 68588-0156

Corresponding author — A. B. Rosen, School of Health, Physical Education and Recreation, University of Nebraska at Omaha, 6001 Dodge St, HPER 207Y, Omaha, NE, 68132, USA.
Email arosen@unomaha.edu

Abstract

Chronic ankle instability (CAI) is often debilitating and may be affected by a number of intrinsic and environmental factors. Alterations in neurocognitive function and attention may contribute to repetitive injury in those with CAI and influence postural control strategies. Thus, the purpose of this study was to determine if there was a difference in attentional functioning and static postural control among groups of Comparison, Coper and CAI participants and assess the relationship between them within each of the groups. Recruited participants performed single-limb balance trials and completed the CNS Vital Signs (CNSVS) computer-based assessment to assess their attentional function. Center of pressure (COP) velocity (COPv) and maximum range (COPr), in both the anteroposterior (AP) and mediolateral (ML) directions were calculated from force plate data. Simple attention (SA), which measures self-regulation and attention control was extracted from the CNSVS. Data from 45 participants (15 in each group, 27 = female, 18 = male) was analyzed for this study. No significant differences were observed between attention or COP variables among each of the groups. However, significant relationships were present between attention and COP variables within the CAI group. CAI participants displayed significant moderate to large correlations between SA and AP COPr ($r = -0.59$, $p = 0.010$), AP COPv ($r = -0.48$, $p = 0.038$) and ML COPr ($r = -0.47$, $p = 0.034$). The results suggest a linear relationship of stability and attention in the CAI group. Attentional self-regulation may moderate how those with CAI control postural stability. Incorporating neurocognitive training focused on attentional control may improve outcomes in those with CAI.

Keywords: Sprain, Neurocognitive function, Center of pressure, Balance

1. Introduction

Ankle sprains are some of the most common sports injuries. Some estimates have the frequency of occurrence at over 23,000 sprains per day in the United States with an approximate cost of $1000 per injury [1,2]. As many as 74% of those who experience an ankle sprain subsequently develop chronic ankle instability (CAI), which is characterized by a persistent dysfunction or recurrence of injury [3]. Chronic ankle instability can lead to further sprains and injury and can contribute to the development of osteoarthritis [4]. In addition, levels of physical activity may be disrupted and decreased which may impact the long-term health of individuals with CAI [5]. Thus, although many consider ankle sprains insignificant, the long-term consequences associated with CAI may exact significant physical and financial tolls.

It is currently unclear why some develop CAI while others do not, but both mechanical and neurological contributions have been suggested. After a sprain, tissue may heal with different mechanical properties, predisposing the joint to a less-than-optimal response to forces and perturbations [6]. Neurologically, it has been found that muscle spindle traffic is decreased in individuals with CAI [7]. The mechanism by which this occurs is unclear, but it is speculated that damage to mechanoreceptors within the joint may result in a lower ability to sense or respond to perturbations. Centrally mediated mechanisms, such as the organization of movement, may be disrupted and predispose an individual to repeated bouts of ankle instability [8]. However, this area of literature is emerging and it remains unclear why one person may develop CAI after a sprain while another may not.

Alterations in neurocognitive processing and function may also influence lower extremity injury. Recent evidence suggests those with altered neurocognitive function due to concussion may have a higher risk of lower extremity injury [9]. Similarly, individuals with a history of non-contact ACL injury have demonstrated worse reaction time, processing speed and memory compared to matched controls [10]. For the ankle specifically, dual-tasking has been used to indirectly assess attentional costs in individuals with CAI with conflicting results. One study previously found comparable time-to-boundary in those with CAI compared to controls during cognitive induced loading [11]. In contrast, another recent investigation found that those with CAI had worse postural control compared to controls with an added cognitive task suggesting a reliance on attentional control in this population [12]. However, this is not well understood because no investigations have directly measured attention in individuals with CAI.

In those with CAI, although attention has not been independently assessed, it may have a relationship to postural control which may not be present in healthy individuals. Attention is described as a limited resource, which must be distributed among all tasks a person is performing, including both motor and cognitive tasks [12]. As one process is provided more attention, another source must have access to less. Consequently, as attention is diverted to a specific task and away from others, performance may suffer. As maintaining static balance is a task requiring attention, those who have higher attentional control or self-regulation and can shift or focus their attention better, may be more efficient at maintaining their balance [13]. Therefore the purpose of this study was two-fold: 1) To identify if there was a relationship between attentional self-regulation and postural control across CAI, Coper and Comparison groups, and 2) To determine if those with CAI had altered attentional control or static postural stability compared to Comparison and Coper participants. It was hypothesized that as attentional self-regulation increased, single limb postural stability would as well and those with CAI would have decreased attentional functioning and postural control compared to Comparison and Coper participants.

2. Methods

2.1. Participants

Participants were recruited as a sample of convenience from the local university population. Participants were recruited into one of three groups; Comparison, Coper or CAI. Participants were entered into the Comparison group if they had 1) no history of lateral ankle sprain, 2) no complaints of their ankle giving way, and 3) a Cumberland Ankle Instability Tool (CAIT) score of _28, indicating good function [14]. For Copers inclusion criteria were 1) a history of a moderate to severe ankle sprain including inflammatory symptoms (pain, swelling, and/or discoloration) and disruption of desired physical activity, 2) 1 or fewer episodes of giving way at the ankle in the previous 12 months, and 3) CAIT score _28 [14,15]. Inclusion criteria for the CAI group included 1) a history of a moderate to severe ankle sprain including inflammatory symptoms (pain, swelling, and/or discoloration) and disruption of desired physical activity, 2) 2 or more episodes of giving way at the ankle in the previous 12 months, and 3) CAIT score _24, suggesting decreased ankle function [16]. In individuals who indicated bilateral instability, the limb with the lower CAIT score was utilized for testing.

All subjects were excluded with any of the following: history of lower extremity surgery or fracture; current sign or symptom of a joint sprain in the lower extremity (including pain, swelling, discoloration, or loss of range of motion or strength); any other health issue or unusual symptom (e.g., nausea, dizziness) that could affect the participant's safety or performance; pregnancy; diagnosis of a vestibular disorder; significant history of condition that impaired cognitive function such as learning disability, concussion, etc.; or if they were taking medications that affected cognitive function such as narcotics, anti-depressants, anti-anxiety agents, etc.

2.2. Procedures

Participants first arrived at the balance laboratory and completed University approved informed consent documents as well as all eligibility questionnaires. Subjects were then placed on a force platform (Neurocom, Balance Master System 8.4, Clackamas, OR, USA; 100 Hz) and asked to stand on the test limb in a quiet stance. For CAI and Coper participants the test-limb was indicated as the previously injured limb, for Comparison their dominant limb was used. Subjects performed 5 trials on their test limb for 60 s per trial. If subjects lost balance, touched the non-standing-foot down, or braced themselves on the surround, the trial was discontinued and recollected.

After the single-leg task, subjects sat in a quiet room and completed the CNS Vital Signs (CNSVS, CNS Vital Signs LLC., Morrisville, NC, USA) on a laptop computer. The CNSVS is a battery of valid and reliable computer-based neurocognitive tests designed to assess standard neuropsychological domains (e.g., memory, attention, psychomotor speed, etc.) [17]. For this study, only the domain of simple attention (SA) was calculated through data from the continuous performance test (CPT). The CPT lasts approximately 5 min and participants are presented one at a time with random letters. 200 letters are presented in total, approximately 1.5 s each. They are asked to respond to the letter "B" (40 times randomly) while ignoring all other letters, the letters continually appear regardless of response. SA is a measure of sustained attention, self-regulation and attention control; it is defined as the ability to track and respond to a single defined stimulus over lengthy periods of time while performing vigilance and response inhibition quickly and accurately to a simple task [17]. It takes into account both attentiveness and inhibition. Instructions and practice assessments were provided during the test; testing took approximately 25 min to complete.

2.3. Data and statistical analysis

A custom written MATLAB (Mathworks, Inc., Natick, MA, USA) script used the force plate's center of pressure (COP) data to calculate average velocity (COPv) of the COP sway and maximum range (COPr) of the COP in both the anteroposterior (AP) and mediolateral (ML) directions. Higher values of range indicate worse postural control whereas lower values of velocity indicated better postural control. Negative values of COPv indicate the posterior and medial directions, respectively.

Upon completion of the CNSVS a report provided age normalized, standard individual scores of various neurocognitive domains. SA is the number of correct responses minus commission (false positive) errors. Higher values indicate improved sustained attention or self-regulation.

All statistical analyses were completed in the Statistical Package for the Social Sciences™ 20.0 (SPSS, Inc., Chicago, IL). An analysis of variance (ANOVA) was used to assess differences in attention and COP variables. Data were then evaluated using Pearson's Correlation Coefficients between COP and attentional variables, with separate analyses for CAI, Coper and Comparison participants, respectively. Statistical significance for all tests were set a-priori to $p = 0.05$. Correlational coefficients were interpreted as <0.3 = small, 0.3–0.5 = moderate and >0.5 = large.

3. Results

This study recruited 48 subjects, 3 of whom were withdrawn: two due to inability to complete the single-limb stance task; the other was disqualified after revealing the presence of an exclusion criterion (history of ankle fracture) post-eligibility. Thus, data from forty-five participants were analyzed; demographic data can be found in **Table 1**. Groups were equivalent for sex, age, height and mass. There were group differences related to injury characteristics: the CAI participants had more ankle sprains ($p < 0.001$) and lower CAIT scores ($p < 0.001$) than Coper and comparisons.

No significant between-group differences were observed across SA and COP variables (**Table 2**). Small significant correlations across all participants were present between attention and AP COPr ($r = –0.362$, $p = 0.007$) as well as AP COPv ($r = 0.274$, $p = 0.034$). However, larger, significant relationships were present between SA and COP variables within the CAI group and one COP measure for the Copers. CAI participants displayed moderate to large significant correlations (**Table 3**) between SA and AP COPr, AP COPv and ML COPr. The Coper group had a significant moderate relationship between SA and AP COPr. No correlations were observed between attention and COP variables in the comparison group.

4. Discussion

The purpose of this study was to identify how attention and postural stability might be related across three groups: those with CAI, those defined as Copers, and a healthy Comparison group. While there were no differences between the groups on any measure of COP or attention, significant correlations were found within the two injury groups, but not the Comparison.

Table 1. Demographic Data.

	Comparison	*Coper*	*CAI*
Female (n)	9	9	9
Male (n)	6	6	6
Age (years)	22.7 ± 2.3	22.1 ± 2.3	22.7 ± 3.4
Height (cm)	171.3 ± 10.3	172.5 ± 10.4	169.8 ± 8.2
Mass (kg)	74.9 ± 12.6	71.1 ± 10.4	70.2 ± 15.4
CAIT	29.9 ± 0.4*	28.4 ± 1.1*	17.5 ± 5.7*
# of Sprains (n)	0.0 ± 0.0*	1.5 ± 0.8*	3.7 ± 3.3*
Initial Injury (mo)	0.0 ± 0.0	55.5 ± 29.5*	45.6 ± 29.6*
Simple Attention	94.7 ± 14.5	95.3 ± 18.9	89.7 ± 13.0

* Indicates significance (p < 0.05).

Table 2. Distributional Statistics for Antero-Posterior and Medio-Lateral Center of Pressure Range and Velocity.

	Antero-Posterior							
	Range (mm)				*Velocity (mm/s)*			
	Mean ± SD	*95% CI*	*F*	*p*	*Mean ± SD*	*95% CI*	*F*	*p*
Comparison	37.33 ± 8.71	32.44, 42.09	0.78	0.47	–0.07 ± 0.18	–0.17, 0.04	0.05	0.96
Coper	41.59 ± 11.67	35.13, 45.05			–0.07 ± 0.14	–0.15, 0.00		
CAI	42.06 ± 13.87	34.37, 49.74			–0.08 ± 0.14	–0.16, 0.00		
	Medio-Lateral							
	Range (mm)				*Velocity (mm/s)*			
	Mean ± SD	*95% CI*	*F*	*p*	*Mean ± SD*	*95% CI*	*F*	*p*
Comparison	30.16 ± 7.12	26.21, 34.10	0.06	0.94	–0.03 ± 0.08	–0.02, 0.01	0.94	0.40
Coper	30.84 ± 6.09	27.46, 34.21			–0.04 ± 0.09	–0.09, 0.01		
CAI	30.85 ± 5.01	28.07, 33.62			0.00 ± 0.07	–0.04, 0.04		

Table 3. Correlation Coefficients between Simple Attention and Antero-Posterior and Medio-Lateral Center of Pressure Range and Velocity.

	Antero-Posterior Direction		*Medio-Lateral Direction*	
	Range	*Velocity*	*Range*	*Velocity*
Comparison	0.195 (p = 0.24)	0.005 (p = 0.49)	0.091 (p = 0.37)	–0.208 (p = 0.23)
Coper	–0.512* (p = 0.03)	0.416 (p = 0.06)	–0.414 (p = 0.06)	0.289 (p = 0.15)
CAI	–0.593* (p = 0.01)	0.483* (p = 0.03)	–0.472* (p = 0.04)	0.343 (p = 0.11)

* Indicates statistical significance (p < 0.05).

The present study found that the CAI, Coper, and Comparison groups had similar static single-leg postural stability values. This finding is in agreement with prior research [18,19], that generally has failed to find any differences in static postural control under single-leg conditions. However, prior research suggests when task demands are altered and made more challenging, then differences begin to emerge between groups. McKeon and colleagues found that single-leg balance with the eyes closed, which effectively eliminates visual input for postural control, caused CAI participants to demonstrate worse postural sway compared to healthy participants [18]. Ross and colleagues also found that static single-leg balance was largely similar between CAI and healthy participants, but a dynamic landing task provided greater discrimination between groups [19]. Thus, patients with CAI appear to be able to maintain appropriate postural stability when balancing on a single leg, so long as the task is controlled and not manipulated. When motion or diminished visual input is added to the task, postural stability suffers in those with CAI.

The importance of attention and attentional focus in patients with CAI has yet to be fully investigated, but the present study does indicate that a correlations exist between poorer attentional self-regulation (as measured by a continuous performance test) and postural stability in patients with CAI (**Figure 1**). Two preceding works [11,12],

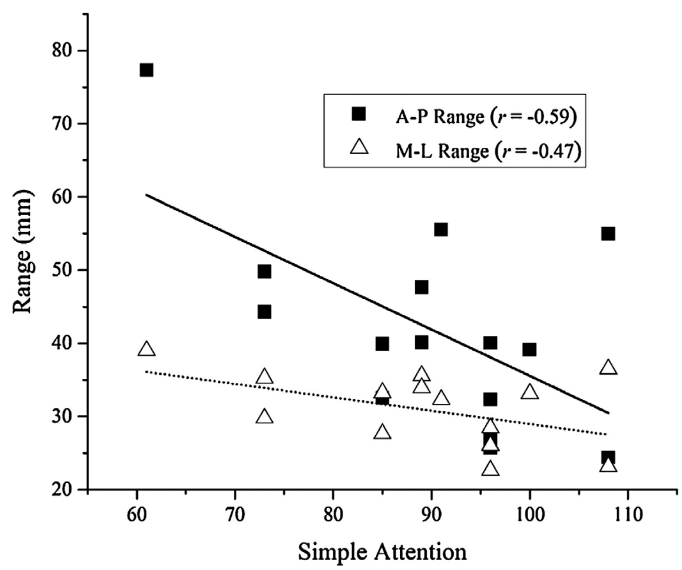

Fig. 1. Scatter plot of anterior-posterior (A–P, solid line) and medial-lateral (M–L, dotted line) center of pressure range versus simple attention of the chronic ankle instability group.

have had conflicting results utilizing dual-task perturbations as insight into attentional cost during static posture. Burcal and colleagues found no differences across groups when a cognitive load was placed on individuals during single-limb balance [11]. However, Rahnama et al. found differences in dual-task performance across controls and CAI suggesting an increased dependency on attentional demands in those with CAI [12]. Perhaps, Comparison, and to some degree Coper participants, are better at self-regulating their attentional resources during single-limb postural control [20]. Although, the cause of this phenomenon remains elusive, and several possible paradigms exist which may explain the differences in underlying attentional regulation of CAI, Coper and healthy static postural control. First, those with CAI could rely more heavily on attention for singular tasks and hence, deficits in attention manifest as postural deficits due to reduced attentional control [12]. Another possible explanation is that those with CAI may put less of an attentional priority on postural control and when attentional control is poor, stability suffers [21,22]. Conversely, perhaps there is no difference between the two groups' weighting or self-regulation of attention in postural control, but rather the ability of each group to shift their attention as necessary, in response to postural perturbations [20].

Clinically, the relationship between attention and postural control may have important implications for individuals with CAI. In the current study a simple, a static balance task was used. Patients with CAI generally demonstrate impaired balance and stability during dynamic tasks [23,24] which often require higher levels of attentional focus and self-regulation. Thus, poorer attentional self-regulation may manifest as poorer postural stability during more demanding tasks and environments. When an individual needs to respond to the surrounding environment such as during dynamic sporting activity where it is required of players to respond quickly to the activity (goal, other competitors, movement, etc.) individuals with lower levels of attentional control may not be able to negotiate and integrate sensory information properly [25]. Correspondingly, a recent study suggests that during simple tasks, such as single-limb eyes open balance does not necessarily require attentional resources in healthy individuals – however, this relationship may be different for those with CAI, and may change during more complicated tasks [26]. Furthering this notion, another study found a relationship between the relative change in

COPv during dual-tasking and the episodes of giving way in the preceding three months to testing in a CAI population [27]. This suggests even within a group of CAI, impairment and self-reported dysfunction may exhibit subtle differences. Thus, this relationship between attention and stability in those with CAI may leave those affected susceptible to injury and may be an individualized response. However, a long-term, prospective study design is warranted to more definitively determine the role attentional self-regulation plays in CAI injury risk.

Although the majority of current ankle rehabilitation programs involve balance training with various perturbations, the addition of neurocognitive training has yet to become a popular choice among sports medicine clinicians for ankle injuries. While several studies have been completed on other populations (such as the elderly, targeting fall prevention with promising results [28–30] this type of training has not yet been effectively integrated into the athletic population for neuromuscular injury prevention, particularly for the ankle. Grooms and colleagues recently proposed compelling evidence for integrating neurocognitive training into ACL prevention programs through a neuroplasticity framework which may also may prove to be beneficial in those with CAI [31]. However, the literature provides little to no evidence regarding the effectiveness of augmented neurocognitive feedback training on decreasing rates of musculoskeletal injury in relatively healthy populations. Potentially, improving attentional self-regulation through neurocognitive training may be warranted and could may improve patient reported outcomes in those with CAI.

4.1. Limitations

We must acknowledge several limitations which may exist with the current study. As mentioned previously, even simple tasks such as static balance require attention and provide insight into deficiencies in processing [32]. However, more difficult tasks may require greater attentional resources and yield greater impairments in those with CAI. In addition, mechanical laxity was not assessed in our CAI population and those with mechanical laxity may have inherent differences as compared to individuals with solely functional impairments [23]. Another potential limitation is that coper groups traditionally do not allow for any episodes of giving in the previous 12 months [15]. While, our inclusion criteria allowed for a maximum of one episode of giving way in the 12 months prior to testing, all coper participants reported no episodes within that time-frame. Lastly, our sample was relatively homogeneous with a predominately college-aged population; older or younger patients with CAI may possess alternate postural control strategies and/or attentional capacities. Future studies may want to assess more difficult, shifting attention or attentional cost tasks and their relationship to attention in CAI participants as well as a wider patient population.

5. Conclusion

These results suggest that in those with CAI attentional control has a strong relationship with COP measures, and as attentional regulation improves, single-limb postural control improves as well. This suggests that attention may play a role in how those with CAI control postural stability. Clinically, attentional control may be necessary to target during rehabilitation to enhance balance or may be used as a clinical tool to better assess risk for those with CAI. Future research should be done to further explore neurocognitive effects on balance, and to determine if neurocognitive training will result in greater priority on stability in CAI patients.

Conflict of interest — The authors affirm that we have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.

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