Background. Neck pain is a widespread complaint. People experiencing neck pain often present an altered timing in contraction of cervical muscles. This altered afferent information elicits the cervico-ocular reflex (COR), which stabilizes the eye in response to trunk-to-head movements. The vestibulo-ocular reflex (VOR) elicited by the vestibulum is thought to be unaffected by afferent information from the cervical spine.

Objective. The aim of the study was to measure the COR and VOR in people with nonspecific neck pain.

Design. This study utilized a cross-sectional design in accordance with the STROBE statement.

Methods. An infrared eye-tracking device was used to record the COR and the VOR while the participant was sitting on a rotating chair in darkness. Eye velocity was calculated by taking the derivative of the horizontal eye position. Parametric statistics were performed.

Results. The mean COR gain in the control group (n=30) was 0.26 (SD=0.15) compared with 0.38 (SD=0.16) in the nonspecific neck pain group (n=37). Analyses of covariance were performed to analyze differences in COR and VOR gains, with age and sex as covariates. Analyses of covariance showed a significantly increased COR in participants with neck pain. The VOR between the control group, with a mean VOR of 0.67 (SD=0.17), and the nonspecific neck pain group, with a mean VOR of 0.66 (SD=0.22), was not significantly different.

Limitations. Measuring eye movements while the participant is sitting on a rotating chair in complete darkness is technically complicated.

Conclusions. This study suggests that people with nonspecific neck pain have an increased COR. The COR is an objective, nonvoluntary eye reflex and an unaltered VOR. This study shows that an increased COR is not restricted to patients with traumatic neck pain.
Neck pain is a major problem worldwide and is a common reason for individuals to seek care from physical therapists and manual therapists. In addition to pain, concomitant symptoms are often present, including headache (65% of cases), dizziness (31% of cases), and visual disturbances. Visual disturbances in people with neck pain may be related to deficits in oculomotor control. In the majority of people with neck pain, a specific cause cannot be identified, and the term "nonspecific neck pain" is used.

People experiencing neck pain often have functional disorders (eg, an altered timing in contraction) of the cervical muscles, such as the longus colli and longus capitis. These cervical muscles provide information to and receive information from the central nervous system. Animal studies have shown that pain has profound effects on muscle spindle afferents. In humans, cervical pain leads to, for instance, a worse joint position sense, indicating disturbed proprioception. Afferent information from the cervical muscles is sent to the vestibular nuclei, where it converges with other information regarding head movements relayed by the visual and vestibular systems. It can be argued that incongruences among the cervical, vestibular, and visual systems are likely to be associated with dizziness and decreased postural stability.

The cervical afferents are not only important for controlling head movements but also involved in the cervico-ocular reflex (COR). The COR stabilizes the eye in response to trunk-to-head movements. The COR operates in conjunction with the vestibulo-ocular reflex (VOR). The VOR stabilizes the eye in response to vestibular input (ie, movements of the head in space). The COR is elicited by proprioception of the facet joints of the cervical spine and deep muscles of the neck. The strength of the COR can be modified as a result of altered visual input and by immobilization of the cervical spine by means of a stiff neck collar. The COR increases in people aged over 60 years as a compensatory mechanism for the sensory loss of the vestibulum. In people with a whiplash-associated disorder (WAD), this compensatory mechanism is not seen. The strength of the COR is increased in people with WAD, but there is no compensatory decline in VOR. To date, no research on COR in people with nonspecific neck pain has been conducted.

Here, we describe the 2 eye movement reflexes (COR and VOR) in people with nonspecific neck pain who are likely to have deficits in neck proprioception.

Therefore, we expect that the COR but not the VOR will be altered when compared with healthy controls.

**Method**

The guidelines of the STROBE statement (STrengthening the Reporting of Observational Studies in Epidemiology) were used for the outline of this report.

**Design Overview**

We conducted a cross-sectional study involving participants with neck pain and healthy controls.

**Setting and Participants**

Participants with neck pain were recruited via physical therapy practices in Rotterdam, the Netherlands. People with nonspecific neck pain were asked personally by their physical therapist to participate in the study. These physical therapists had been briefed about the study and had information letters for the patients. If patients formally consented to being contacted by the investigator (J.V. or B.K.I.), the physical therapist contacted the investigator. Healthy controls were recruited by means of an information letter spread among coworkers, students, and other people in Erasmus MC and the Rotterdam University of Applied Sciences having no personal or legal relationship with the investigator. All participants were recruited and tested between October 2012 and September 2014. All participants gave prior written informed consent.

In all participants, cervical range of motion (CROM) was measured with a CROM device (Performance Attainment Associates, Lindstrom, Minnesota). The CROM device consists of a magnet and 3 compass-like instruments positioned in the 3 directions of neck mobility (rotation, flexion/extension, and lateroflexion). The CROM measures the maximum range of motion (in degrees) in each of these directions.

**Recording of Reflexive Eye Movements**

Monocular eye (left) positions were recorded by infrared video-oculargraphy (Eyelink 1, SMI, Berlin, Germany) at a sample rate of 250 Hz. Eye position was calibrated using the built-in 9-point calibration routine. Eye movements were
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Figure 1.
A schematic representation of the experimental setup. In both paradigms, the participant had to look at a position directly in front of the setup. For the cervico-ocular reflex, the participant’s body was rotated while the participant’s head was held fixed relative to the floor to fixate the position of the head in space. For the vestibulo-ocular reflex, the participant’s body was rotated while the participant’s head was held fixed relative to the chair.

recorded during either cervical or vestibular stimulation in complete darkness by rotating the chair in which the participant was seated. The chair was attached to a motor (Harmonic Drive, Limburg/Lahn, Germany) that ensured sinusoidal chair rotation without any backlash. The trunk was fixed to the chair at shoulder level by a double-belt system. A sensor connected to the chair recorded chair position and stored the data on a computer along with eye positions.

In both stimulation paradigms (COR and VOR), participants were instructed to keep their eyes open during the stimulation and to look at a position directly in front of the setup. This position was briefly indicated by means of a laser dot before the rotation started. Head position was fixed in both conditions by means of a custom-made biteboard. In both stimulation paradigms, the position of the biteboard was set so that the axis of rotation was under the midpoint of the interaural line.

During the COR stimulation, the biteboard was mounted to the floor to fix the position of the head in space (Fig. 1). Rotation of the chair induced pure cervical stimulation, which elicits the COR in isolation. The chair was rotated for 134 seconds around the vertical axis with an amplitude of 5.0 degrees and a frequency of 0.04 Hz. This approach yielded 5 full sinusoidal rotations of the chair with a peak velocity of 1.26 degrees per second. During the VOR stimulation, the biteboard was mounted to the chair so that rotation of the chair induced pure vestibular stimulation (Fig. 1). The chair was rotated for 33 seconds around the vertical axis with an amplitude of 5.0 degrees and a frequency of 0.16 Hz. This approach yielded 5 full sinusoidal rotations of the chair with a peak velocity of 5.03 degrees per second.

Data Processing and Analyses
Eye velocity was calculated by taking the derivative of the horizontal eye position signal. After removal of blinks, saccades, and fast phases (using a 20°/s threshold), a sine wave was fitted through the eye velocity signal data. Stimulus velocity was derived from chair position (COR and VOR measurement) data. The gain of the response was defined as the amplitude of the eye velocity fit divided by the peak velocity of the chair rotation (COR: 1.26°/s, VOR: 5.03°/s). Therefore, a gain of 1 reflects that the peak velocity of the eye was the same as the peak velocity of the chair rotation. All data processing was done with Matlab R2013a (The MathWorks Inc, Natick, Massachusetts).

Data Analysis
Descriptive statistics were computed for the entire sample for the gains of the COR and VOR (outcome parameters), NDI, DHI, perceived pain, CROM (outcome variables), and age and sex (possible confounders). As the data was distributed normally (Kolmogorov-Smirnov test), parametric statistics were applied. Two analyses of covariance (ANCOVAs) were performed to analyze differences in COR and VOR gains, respectively, between healthy controls and participants, with neck pain with age and sex as covariates. Correlations between the gains (outcome parameters) and outcome variables were assessed using Pearson correlation coefficients. An alpha level of 0.05 was considered significant for all statistical tests. The data were analyzed with IBM SPSS Statistics for Windows, version 22 (IBM Corp, Armonk, New York).

Role of the Funding Source
The authors are grateful for the financial support of TC2N (EU Interreg; Professor Dr Frens and Dr van der Geest), and Stichting Coolingsel (Professor Dr Frens).

Results
Forty-one participants with neck pain and 30 healthy controls participated in the study. Eye movement recordings were successful in 37 participants with neck pain. In 2 participants, it was not possible to track the eye of the participant; in 1 participant, calibration of the eye tracking failed, and in 1 participant, we failed to store the data properly on the hard disk.

Group characteristics are presented in tabular format (Table). Healthy controls were on average 13.8 years younger than participants with neck pain. There was a correlation between the VOR gain and age in the control group (r = .370, P = .048). In the neck pain group, there was no correlation between the VOR...
gain and age ($r = -0.163, P = 0.364$). No other correlations among age, COR gain, VOR gain, and CROM were found in each group (all $r$ values $< 0.291$).

Participants with neck pain showed an increased COR after controlling for age and sex ($F_{1,62} = 4.15, P = 0.046, \eta^2 = 0.063$), but no significant difference in VOR ($F_{1,58} = 1.66, P = 0.203, \eta^2 = 0.028$) when compared with healthy controls. Cervical range of motion was reduced in participants with nonspecific neck pain in the vertical plane (flexion/extension, $F_{1,60} = 4.21, P = 0.045, \eta^2 = 0.066$), but not in the horizontal plane (rotation, $F_{1,60} = 0.33, P = 0.568, \eta^2 = 0.005$).

The correlation between the gains of the 2 eye movement reflexes was not significant when the data were pooled ($r = 0.211, P = 0.102$) (Fig. 2) or analyzed per group, neck pain group ($r = 0.304, P = 0.091$), and in the control group ($r = 0.152, P = 0.431$).

In addition, correlations between the COR or VOR and pain levels, location of the neck pain, range of motion of the cervical spine, NDI scores, or DHI scores were not significant ($r$ values between $0.037$ and $-0.233$, all $P$ values $> 0.172$). The correlation between COR gain and pain level at the moment of measurement was close to significance ($r = -0.304, P = 0.07$).

**Discussion**

We observed a higher COR but an unaltered VOR in a group of participants with neck pain compared with a group of healthy controls. This is the first study, to our knowledge, investigating the COR in nontraumatic neck pain. Similar results were obtained in a previous study in people with WAD. This finding suggests that an increased COR is not restricted to specific patient groups with neck pain.

An explanation for an increased COR in people with neck pain could be altered afferent information from the cervical spine. In the cervical spine, the information from muscles is a dominant source of information. Deficits in afferent information are suggested by magnetic resonance imaging studies showing a widespread presence of fatty infiltrates in the neck muscles of patients with chronic whiplash and to a lesser extent in patients with idiopathic neck pain. Furthermore, muscles of the cervical spine (especially in the suboccipital region) have an exceptionally high density of muscle spindles. An alteration of afferent information of the cervical spine is therefore likely to affect the COR.

Another explanation is that people with neck pain avoid movements in the end range of motion. This avoidance of move-

### Table.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Control Group (n=30)</th>
<th>Neck Pain Group (n=37)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{X}$ (SD)</td>
<td>95% CI</td>
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<tr>
<td>Age (y)</td>
<td>28.3 (9.1)</td>
<td>25.7, 32.3</td>
</tr>
<tr>
<td>Male/female, n</td>
<td>15/15</td>
<td>12/25</td>
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<tr>
<td>Cervico-ocular reflex</td>
<td>0.26 (0.15)</td>
<td>0.21, 0.32</td>
</tr>
<tr>
<td>Vestibulo-ocular reflex</td>
<td>0.67 (0.17)</td>
<td>0.61, 0.74</td>
</tr>
<tr>
<td>CROM rotation</td>
<td>139 (18)</td>
<td>133, 146</td>
</tr>
<tr>
<td>CROM flexion/extension</td>
<td>133 (23)</td>
<td>123, 139</td>
</tr>
<tr>
<td>Pain</td>
<td>4.1 (2.0)</td>
<td>3.5, 4.8</td>
</tr>
<tr>
<td>Neck Disability Index</td>
<td>23.4 (12.8)</td>
<td>20.5, 28.4</td>
</tr>
<tr>
<td>Dizziness Handicap Inventory</td>
<td>18.2 (17.3)</td>
<td>12.3, 24.7</td>
</tr>
</tbody>
</table>

$^a$ CROM=cervical range of motion, CI=confidence interval. Neck Disability Index scores range from 0 (no disability) to 100 (maximal disability). Dizziness Handicap Inventory scores range from 0 (no disability) to 100 (maximal disability). Age and sex were identified as possible confounders. $^b$ Significant difference between control group and neck pain group at $P<0.05$.

**Figure 2.**

Scatterplot of the cerviculo-ocular reflex (COR) and vestibulo-ocular reflex (VOR) for all participants.
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measure also could alter afferent information of the cervical spine and, in turn, affect the COR. Our data suggest that this may be the case for the vertical plane, where we observed a reduction in the range of motion in participants with neck pain. However, the higher age in the nonspecific neck pain group also could explain the reduced range of motion. In the rotational plane, there was no difference between the 2 groups, in contrast to other studies. This difference could be explained by the low-to-moderate neck pain and disability levels in our neck pain group.

Normally, the afferent information from the vestibular and cervical system cooperate in order to maintain a clear visual image during head and eye movements. Our findings suggest that the VOR does not compensate for the increased COR in the neck pain group. This mismatch between COR and VOR could lead to visual disturbances, dizziness, and postural control disturbances. In our study, we found no correlation among pain levels, dizziness, and the COR. This lack of correlation could be explained by the fact that the study population scored rather low on both the DHI and NPRS.

Measuring eye movements in patients may be useful for diagnostic and therapeutic purposes. For instance, it is not possible to influence COR deliberately, which makes the COR an objective outcome measure of oculomotor function that could be used as an additional test in clinical settings. This objectivity contrasts with other rather subjective outcome measures used to diagnose neck pain, such as questionnaires on disabilities and pain intensity. However, objectively quantifying the ocular reflexes also has some limitations. For instance, eye movements need to be measured with adequate precision and accuracy. In the present study, we measured reflexive eye movements by means of video-oculography. Measuring eye movements while the participant is sitting on a rotating chair in complete darkness is technically complicated. Furthermore, video-oculography is rather expensive. A cheaper and easier way to measure eye movements is by means of electro-oculography. Although this method is widely used in clinical settings, it is less suitable for recording VOR and COR eye movements due to its limited accuracy and reliability.

Another limitation is related to the fact that we only observed group effects. It would be interesting to investigate the possibility of assessing oculomotor control on an individual level or as part of a function profile of people with neck pain. Another interesting question yet to be answered is whether it is possible to use the COR as an outcome measure to evaluate the effectiveness of interventions in people with neck pain. In a future study, we will make a direct comparison of the COR among people with nonspecific neck pain, people with WAD, and people without neck pain. It may well be that there is a difference in the COR among these groups. Another interesting direction for future research could be to investigate the relationship between COR and visual complaints, which occur frequently in people with neck pain.

We conclude that a deficit in eye stabilization function, namely an increased COR, can be observed in patients with neck pain without any direct causes (i.e., nonspecific neck pain). We suggest that the evaluation of oculomotor control in patients with neck pain and concomitant symptoms, such as decreased postural stability, may be worthwhile in clinical settings.

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The study was approved by the local ethical board of Erasmus MC.

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