A pragmatic randomised trial of stretching before and after physical activity to prevent injury and soreness

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ABSTRACT

Objective: To determine the effects of stretching before and after physical activity on risks of injury and soreness in a community population.

Design: Internet-based pragmatic randomised trial conducted between January 2008 and January 2009.

Setting: International.

Participants: 2,377 adults who regularly participated in physical activity.

Interventions: Participants in the stretch group were asked to perform 30-second static stretches of 7 lower limb and trunk muscle groups before and after physical activity for 12 weeks. Participants in the control group were asked not to stretch.

Main outcome measurements: Participants provided weekly on-line reports of outcomes over 12 weeks. Primary outcomes were any injury to the lower limb or back, and bothersome soreness of the legs, buttocks or back. Injury to muscles, ligaments and tendons was a secondary outcome.

Results: Stretching did not produce clinically important or statistically significant reductions in all-injury risk (HR = 0.97, 95% CI 0.84 to 1.13), but did reduce the risk of experiencing bothersome soreness (mean risk of bothersome soreness in a week was 24.6% in the stretch group and 32.3% in the control group; OR = 0.69, 95% CI 0.59 to 0.82). Stretching reduced the risk of injuries to muscles, ligaments and tendons (incidence rate of 0.66 injuries per person-year in the stretch group and 0.88 injuries per person-year in the control group; HR = 0.75, 95% CI 0.59 to 0.96).

Conclusion: Stretching before and after physical activity does not appreciably reduce all-injury risk, but probably reduces the risk of some injuries, and does reduce the risk of bothersome soreness.

Trial registration: anzctr.org.au 12608000044325.

Many people stretch before or after exercise, generally with the expectation that stretching lessens post-exercise soreness, reduces the risk of injury, increases the sense of "looseness" or wellbeing, or enhances performance. Surprisingly, given the popularity of stretching, the effects of stretching have not been clearly established.

A review of randomised studies of the effects of stretching on *risk of injury* published before February 2000 concluded, on the basis of two large randomised trials, that "stretching before exercising does not seem to confer a practically useful reduction in the risk of injury, but the generality of this finding needs testing".[1] Three further systematic reviews of stretching on injury risk have been conducted.[2 3 4] All three concluded the available evidence was not conclusive. To our knowledge there have been no further randomised trials of the effects of stretching before or after physical activity on risk of injury, although we are aware of another trial that is currently underway.[5]

Recently we systematically reviewed studies of the effects of stretching on *muscle soreness* published before May 2006.[6] We identified 10 mostly small studies. Pooled estimates of effects were small and not statistically significant. For example the effect of pre-exercise stretching was to reduce soreness one day after exercise by, on average, 0.5 points on a 100-point scale (95% CI -11.3 to 10.3; 3 studies). Post-exercise stretching reduced soreness one day after exercise by, on average, 1 point on a 100-point scale (95% CI -7 to 5; 4 studies). Similar effects were evident between half a day and three days after exercise. It was concluded that the best available evidence indicates stretching does not reduce muscle soreness.

The studies identified in these reviews have at least two limitations. First, the studies were carried out on populations that may not be representative of recreationally active people. The two trials of stretching to prevent injury risk enrolled army recruits undergoing basic military training and nine of the 10 studies of stretching to prevent muscle soreness involved participants in whom muscle soreness was induced with eccentric exercise in laboratory settings. It is not clear if the findings of these studies are applicable to the broader population of people who stretch before or after physical activity. A second limitation is that the existing studies of effects of stretching on muscle soreness have investigated the effects of a single session or a very short program of stretching (maximum of 12 sessions over three days). However the effects of stretching may accumulate over time, in which case trials of short duration may fail to detect real effects.

Our informal surveys suggest that some people stretch before or after participating in physical activity because they feel it enhances their sense of well-being or "looseness" or preparedness to exercise. These effects have not been investigated in randomised trials.

We conducted a randomised trial of stretching in a community population of physically active people. Our primary objectives were to determine if a program of stretching before and after vigorous physical activity reduces risk of injury or soreness. Secondary objectives were to determine effects of stretching on severity of soreness and feelings of looseness during and after exercise, and to ascertain if the magnitude of effects on injury risk or soreness depend on age, activity levels or beliefs about the effectiveness of stretching.

METHODS

The trial was a pragmatic internet-based randomised trial. It was registered prospectively (ANZCTRN: 12608000044325; full protocol available at www.stretchingstudy.nokc.no). As

the study was entirely internet-based it was possible to recruit a large and diverse sample of physically active people from a community population. The trial was managed from the main office in Norway and a second office in Sydney. Ethical approval was given by the University of Sydney Human Ethics Review Committee. The Regional Committee for Medical Research Ethics in Norway ruled that it was not necessary to obtain ethical approval from that body.

Study sample: Participation was open to people anywhere in the world who satisfied the following criteria: aged 18 years or over, able to read and write in English or Norwegian, takes part in vigorous physical activity on at least one day in the past week, and regularly accesses internet and email. People who reported a lower limb or back injury that restricted participation in vigorous physical activity were excluded. People were made aware of the trial through a television program on health in Norway and a radio program on health in Australia, as well as by email messages sent to individuals and associations.

Procedures: Potential participants visited the trial web site and were screened for eligibility. Those who were eligible were asked to log on to the web site on the following Sunday and complete a questionnaire about their age, physical activity, stretching habits, and beliefs regarding the effects of stretching. After completing this questionnaire participants were randomised to the stretch or control group. The randomisation schedule was unrestricted (no stratification or blocking) and was administered by computer. This ensured the randomisation sequence was concealed.

For the following 12 weeks each participant was sent a weekly email reminder to visit the trial web site. A second reminder was sent to those who did not respond within four days. Using the web site, participants provided details about soreness, perceptions of "looseness" (or, in Norwegian, "løs og ledig") during and after exercise, amount of vigorous activity, compliance with the trial protocol, and adverse events. Participants who experienced an injury of the lower limb or back in the past week were asked to provide details about the injury, using an adaptation of the groupings and categories recommended by Fuller and colleagues.[7]

As the trial was entirely web-based there were no meetings between participants and investigators. Participants were able to contact the investigators by email if they had questions.

Interventions: Participants in the *stretch group* were asked to stretch seven muscle groups (gastrocnemius, hip adductors, hip flexors, hamstrings, rectus femoris, hip external rotators and trunk rotators) on both sides of the body before and after every occasion of vigorous physical activity. The stretches were designed by physiotherapists and physical training instructors. A detailed description of the stretches is available from the authors. Each muscle or muscle group was stretched using a static stretch of at least 30 seconds and was of sufficient intensity that, for the duration of the stretch, the participant felt a strong but not painful stretch. Thus the stretching protocol took at least 14 minutes. The stretches were explained using images and text on the trial web site, and participants were able to print out a credit card-sized pamphlet explaining how to do the stretches. Participants were asked not to stretch any other lower limb or trunk muscle groups for the 12 week period.

Participants in the *control group* were asked not to stretch any lower limb or trunk muscles over the 12 week period.

Participants in *both groups* were instructed to continue their usual exercise patterns and their usual stretching routines for upper limbs. Participants who, prior to the study, normally

warmed up prior to exercise or warmed down after exercise continued to perform normal warm-up or warm-down routines unless part of the warm-up or warm-down procedure provided significant stretch to the lower limbs or trunk, in which case that part of the warm-up or warm-down was discontinued for the duration of the trial.

Outcomes: The primary outcomes were time to injury and soreness. Each week participants were asked if they had experienced a lower limb or back injury, even if the injury was unrelated to exercise. If so, they indicated date, type and site of injury, and the type of activity that induced the injury. Participants were also asked if they had experienced bothersome soreness in the legs, buttocks or back in the preceding week.

Secondary outcomes included time to muscle, ligament and tendon injuries, time to injuries for which professional care was sought ("professional care injuries"), severity of soreness, and perceptions of "looseness" during and after exercise. Participants rated the worst soreness they experienced in the legs, buttocks or back in the preceding week using a 0-10 scale anchored at "no soreness" and "worst imaginable soreness". Looseness was rated on a similar scale anchored at "completely loose" and "not loose at all".

Statistical analysis: The focus was on estimation of the size of the effect of stretching, rather than hypothesis testing. Analysis was by intention to treat. Missing soreness data were imputed by carrying the last observation forward and the first observation backward. A sensitivity analysis was performed to determine the degree to which imputation influenced the findings.

The analyses of primary outcomes were conducted separately by two statisticians using different software (SAS v9.2 and Stata v9.2). The allocation code was not broken until the analyses were compared and found to yield the same results. Time to first *injury* was compared using Cox regression. As not all participants completed all reports we used a risk window approach that allowed the risk period for an individual to be interval-censored. Confidence intervals were calculated using robust (sandwich) variance estimators. Generalised estimating equations were used to estimate parameters of a linear model of the log odds of having *bothersome soreness*. The variables in the model were group membership, time, and group by time interactions. Time was modelled as a categorical variable (13 time points dummy coded as 12 variables).

A test of the effects of stretching on a second measure of muscle soreness used participants' weekly ratings of the severity of muscle soreness. Again, longitudinal models (mixed linear models with random intercepts for participants) were used. The same approach was used to determine effects of stretching on perceptions of looseness. Additional secondary outcomes were time to muscle, ligament and tendon injuries and time to professional care injuries. Further analyses investigated whether frequency of physical activity at baseline, or age, or strength of belief in the importance of stretching modified (interacted with) effects of stretching on soreness and risk of injury. Age was entered into these models as a continuous variable. Altogether two primary outcomes and 12 secondary outcomes were specified a priori in the analysis plan.

Sample size: The target sample size was 2,321. With the Type I error rate set at 5%, this sample size provides an 80% probability of detecting a reduction in injury proportion from 12% to 8% (NNT of 25 in 12 weeks) assuming exponential hazards and a loss to follow-up of 20%.[8] The sample size also provides 80% power to detect a reduction in the risk of

experiencing muscle soreness from 15% to 12% (NNT of 33) assuming a loss to follow-up of 20% and an intra-cluster (within-participant) correlation of 0.4.[9]

RESULTS

Participants: 2,377 people were randomised to either the stretch group (n = 1,220) or control group (n = 1,157) between 21 January 2008 and 2 November 2008. Characteristics of participants are given in Table 1. The mean age was 40 years. Nearly two-thirds were women and over half reported their nationality was Norwegian. When asked what was the most vigorous regular activity, about one-third nominated running and one-fifth nominated going to the gym. Participants engaged in physical activity a median of 4 times per week (IQR 3 to 5 times; Table 2). The groups appeared to be well matched at baseline.

Table 1. Characteristics of participants in stretch (n = 1,220) and control (n = 1,157) groups.

		Stretch group	Control group
Gender	female	763 (62.5)	749 (64.7)
Age	mean (SD)	39.8 (12.6)	40.0 (12.5)
Nationality	Norwegian	662 (54.3)	638 (55.1)
	Australian	235 (19.3)	250 (21.6)
	Other	323 (26.5)	269 (23.2)
Average number of sessions of physical activity each week	once per week	41 (3.4)	26 (2.3)
	twice	216 (17.8)	202 (17.6)
	3 times	411 (33.8)	370 (32.1)
	4 times	230 (18.9)	251 (21.8)
	5 times	195 (16.0)	185 (16.1)
	6 times	71 (5.8)	59 (5.1)
	> 6 times per week	51 (4.2)	58 (5.0)
Average duration of a session of physical activity	< 30 mins	39 (3.2)	48 (4.2)
	30 - 60 mins	758 (62.4)	719 (62.5)
	> 60 mins	418 (34.4)	384 (33.4)
Most vigorous type of physical activity	running	387 (31.9)	373 (32.4)
	cross-country skiing	33 (2.7)	32 (2.8)
	downhill skiing	1 (0.1)	2 (0.2)
	walking	36 (3.0)	31 (2.7)
	cycling	178 (14.7)	157 (13.6)
	ball games	86 (7.1)	84 (7.3)
	aerobics	78 (6.4)	72 (6.3)
	gym	260 (21.4)	224 (19.5)
	friskis & svettis	61 (5.0)	68 (5.9)
	other	95 (7.8)	108 (9.4)
Do you normally warm up?	always	557 (45.8)	557 (48.4)
	now and then	479 (39.4)	423 (36.8)
	never	179 (14.7)	171 (14.9)
It is important to stretch when doing vigorous physical activity	strongly disagree	46 (3.8)	45 (3.9)
	disagree	140 (11.5)	118 (10.3)
	neither	449 (37.0)	420 (36.5)
	agree	406 (33.4)	402 (34.9)
	strongly agree	174 (14.3)	166 (14.4)
Normally stretch	yes	656 (53.8)	616 (53.2)
Do you enjoy	enjoy	336 (51.2)	330 (53.6)

stretching?	neither	280 (42.7)	260 (42.2)
	dislike	40 (6.1)	26 (4.2)
Reason for stretching	reduce soreness	192 (34.6)	185 (30.0)
	enhance performance	111 (20.0)	116 (18.8)
	reduce risk of injury	99 (17.8)	107 (17.4)
	enhance sense of well-being	78 (14.1)	73 (11.9)
	increase feeling of looseness	12 (2.2)	19 (3.1)
	other	63 (11.4)	116 (18.8)
Timing of stretches	before	60 (9.2)	42 (6.9)
	after	453 (69.6)	425 (69.6)
	before and after	138 (21.2)	144 (23.6)
Duration of stretch	< 5 mins	108 (16.6)	100 (16.4)
	5-10 mins	395 (60.7)	368 (60.2)
	> 10 mins	148 (22.7)	143 (23.4)

Data are counts (% of group in brackets) except where indicated. Some baseline data were missing for 11 participants (0.5% of the sample). Total counts for the last four items are substantially less than the total sample because this question was only answered by those who normally stretch.

Completeness of follow-up and compliance: Most participants provided some reports of injury and bothersome soreness (89.4% and 97.7% of participants respectively). However many participants did not complete all weekly reports and not all reports were complete (Table 2). The completeness of reporting is given in Figure 1. Overall, participants completed 75.9% of the required injury reports and 72.1% of the required bothersome soreness reports. Completeness of reporting was similar in the two groups.

Table 2. Completeness of data, number of exercise sessions, and outcomes by group.

	Stretch group	**Control group**	**Total**
Number of diary entries[1] [mean (SD)]	9.9 (3.5)	10.3 (3.1)	10.1 (3.4)
Sessions of physical activity per week[2]			
No sessions	6	6	12
1 session	35	14	49
2 sessions	110	82	192
3 sessions	248	211	459
4 sessions	241	268	509
5 sessions	191	212	403
6 sessions	119	126	245
7 or more sessions	115	110	225
Missing	14	17	31
At least one leg or back injury	339	348	687
Incidence rates (per person-year)			
all (first leg and back) injuries	2.38	2.44	2.41
muscle, ligament and tendon injuries	0.66	0.88	0.77
professional care injuries	0.35	0.36	0.36

Risk of bothersome soreness in a week[3]	24.6%	32.3%	28.3%
Severity of soreness [mean (SD)][4]	2.5 (2.2)	2.9 (2.5)	2.7 (2.4)
Looseness during activity [mean (SD)][4]	3.0 (2.1)	3.3 (2.3)	3.2 (2.2)
Looseness after activity [mean (SD)][4]	3.2 (2.2)	3.7 (2.4)	3.4 (2.3)

Data are from the 2,125 participants (1,046 in the stretch group and 1,079 in the control group) who provided outcome data. Some provided outcome data but did not provide data on number of sessions of physical activity; these are listed as Missing in the third row of the table.
[1] Number of completed or partially completed diary entries after randomisation (maximum = 12).
[2] Most frequently reported number episodes over the 12 weekly reports.
[3] Mean of all 12 risk estimates.
[4] Mean and SD of all reports (up to 12 observations per participant).

Compliance was moderate. According to self-reports of participants in both groups, 59.2% of participants (38.4% of stretch group and 80.8% of the control group) always complied fully or near-fully with the target frequency of stretching (all sessions of physical activity for the stretch group, none for the control group) and 43.9% of participants (7.7% of stretch group and 81.3% of the control group) always complied fully or near-fully with the target duration of stretching (>10 minutes for the stretch group, none for the control group). Most of the other participants partially complied with the target frequency and duration. Less than 4% did not comply at all (Table 3).

Table 3. Compliance with the stretch protocol by group.

		Stretch group	Control group	Total
Frequency of stretching	Compliant	414 (38.4%)	845 (80.8%)	1259 (59.2%)
	Partially compliant	655 (60.7%)	135 (12.9%)	790 (37.2)
	Non-compliant	10 (0.9%)	66 (6.3%)	76 (3.6%)
Duration of stretching	Compliant	83 (7.7%)	850 (81.3%)	933 (43.9%)
	Partially compliant	986 (91.4%)	132 (12.6%)	1118 (52.6%)
	Non-compliant	10 (0.9%)	64 (6.1%)	74 (3.5%)

Data are from the 2,125 participants (1,046 in the stretch group and 1,079 in the control group) who provided outcome data. Every week participants were asked “On the occasions you did physical activity in that week, how often did you stretch your lower limb or back muscles?” They could answer “Never”, “Rarely”, “On some occasions” or “On most or all occasions”. Participants in the stretch group were defined as compliant if they always responded “on most or all occasions” and non-compliant if they always responded “never”, and participants in the control group were defined as compliant if they always responded “never” and non-compliant if they always responded they stretched at least “rarely”. Participants were also asked “How long did you stretch on each occasion in that week?”. They could respond “I did not stretch”, “less than 5 minutes”, “5-10 minutes” or “More than 10 minutes”. Participants in the stretch group were defined as compliant if they always responded “more than 10 minutes” and non-compliant if they always responded “I did not stretch”, and participants in the control group were defined as compliant if they always responded “I did not stretch” and non-compliant if they always responded they did at least some stretching.

Outcomes – all participants: Altogether 687 participants experienced at least one injury during the course of the trial (Table 2). The incidence rate (counting only the first injury for each participant and taking into account censoring) was 2.41 injuries per person-year for all injuries, 0.77 injuries per person-year for muscle, ligament and tendon injuries, and 0.36 injuries per person-year for professional care injuries. Just over one-quarter of participants reported bothersome soreness in any week (mean risk of 28.3% over the 12 weeks).

Primary outcomes: Stretching did not have a clinically important or statistically significant effect on risk of all injuries (HR = 0.97, 95% CI 0.84 to 1.13; p = 0.69; Table 2; Figure 2A). However stretching produced small reductions in the risk of bothersome soreness. The effect was apparent in the first weekly report and remained nearly constant over the 12 weeks (Figure 2B). The overall odds ratio (mean of the 12 estimates) was 0.69 (95% CI 0.59 to 0.82; p = 0.003). Mean risk of bothersome soreness over the 12 weeks was 24.6% in the stretch group and 32.3% in the control group, so the risk difference was 7.8%. An analysis conducted without imputation of missing data generated very similar results.

Secondary outcomes: Stretching reduced the risk of muscle, ligament and tendon injuries (incidence rate of 0.66 injuries per person-year in the stretch group and 0.88 in the control group, difference of 0.22 injuries per person-year; HR = 0.75, 95% CI 0.59 to 0.96; p = 0.03; Figure 2C). There was not evidence of an effect of stretching on professional care injuries (HR = 0.95; p = 0.76).

Stretching reduced severity of soreness by a mean of 0.4 points on the 0-10 soreness scale (95% CI 0.2 to 0.5). It also increased the perception of looseness during activity by a mean of 0.3 points on the 0-10 looseness scale (95% CI 0.1 to 0.4), and increased the perception of looseness after activity by a mean of 0.4 points (95% CI 0.3 to 0.6).

Interactions: There was a statistically significant interaction between age and effect of stretching on all-injury risk (p of interaction term = 0.039). Thus the hazard ratio of the effect of stretching on all-injury risk was 0.75 (95% CI 0.56 to 0.995) in 20 year olds, 0.97 (95% CI 0.84 to 1.13) in 40 year olds, and 1.26 (95% CI 0.94 to 1.68) in 60 year olds.

There was also a statistically significant interaction between belief in the effectiveness of stretching and the effects of stretching on risk of bothersome soreness (p of test of the 12 interaction terms = 0.034). Thus the odds ratio for the effect of stretching on bothersome soreness was 0.38 (95% CI 0.20 to 0.72) in people who strongly agreed that it was important to stretch when doing physical activity, and 0.82 (95% CI 0.66 to 1.02) in people who strongly disagreed that it was important to stretch.

There was no evidence of an interaction between age and effect of stretching on risk of bothersome soreness (p = 0.11), between belief of effectiveness of stretching and effect of stretching on all-injury risk (p = 0.50) or between frequency of physical activity at baseline and effects of stretching on either all-injury risk or risk of bothersome soreness (p = 0.17 and 0.26 respectively).

DISCUSSION

This is the first randomised trial to examine the effects of stretching on injury risk and muscle soreness in a community population participating in physical activity. We found that stretching does not reduce the risk of all lower limb injuries combined, although it probably

reduces the risk of injuries to muscles, ligaments and tendons. Stretching produces small reductions in the risk of experiencing bothersome soreness.

Effects of stretching on risk of injury: Stretching did not produce statistically significant reductions in all-injury risk. This finding is consistent with the findings of two earlier randomised trials which examined the effect of stretching on all-injury risk in army recruits undergoing basic training.[10 11] Those trials found that stretching did not produce worthwhile reductions in all-injury risk.

An analysis of secondary outcomes suggested that stretching produces statistically significant reductions in the risk of muscle, ligament and tendon injuries. In this population (estimated incidence rate of muscle, ligament and tendon injuries of 0.77 injuries per person-year) the effect was to reduce risk by 0.22 injuries per person-year. Thus one injury to muscle, ligament or tendon was prevented for every 20 people who stretched for 12 weeks.

The finding of an effect of stretching on muscle, ligament and tendon injury risk needs to be considered cautiously because muscle, ligament and tendon injury risk was a secondary outcome, and there was not evidence of an effect of stretching on the primary outcome of all-injury risk. If stretching had reduced the risk of muscle, ligament and tendon injuries without increasing the risk of other injuries we would expect a reduction in all-injury risk. Nonetheless, it is plausible that stretching reduces muscle, ligament and tendon injuries and it may be implausible that stretching increases other injuries.

Other analyses suggested that stretching reduced risk more, in relative terms, in young adults than it did in older adults. Again caution is required when interpreting this finding because age was one of three modifying factors that we tested, and the effect was not very significant ($p = 0.039$). It is also possible the interaction could be explained by confounders.

Effects of stretching on risk and severity of soreness and perceptions of looseness: Stretching reduced the risk of bothersome soreness. In this population (average control group risk of bothersome soreness of 32.3%) stretching prevented, on average, bothersome soreness in one in 13 people each week.

We observed statistically significant effects on severity of soreness and on looseness but they were small. A recent Cochrane review of 10 small randomised studies concluded that stretching did not reduce severity of soreness. All but one of the studies included in the Cochrane review were laboratory studies that examined the effect of just one or two sessions of stretching on soreness induced by a laboratory exercise protocol. Despite the obvious differences between the earlier studies and the current trial, the findings of the current trial are, nonetheless, quantitatively consistent with the findings of those earlier studies. The pooled estimate of the effect of stretching from the four studies in the Cochrane review that measured soreness one day after exercise was that stretching reduced soreness by, on average, 0.1 points on a 0-10 scale (95% CI -0.5 to 0.7; data converted from the original 100-point scale) and the estimate from the current trial was that stretching reduced soreness by an average of 0.3 points (95% CI 0.1 to 0.4).

Limitations: There are at least two risks of bias in this trial. First, some participants did not provide reports of outcomes, and some participants who did provide reports supplied incomplete data, so altogether participants provided 75.9% of required injury reports and 72.1% of required bothersome soreness reports. Loss to follow-up can produce bias in randomised trials.[12] However it would appear unlikely that loss-to-follow-up has substantially

biased estimates of the effects of stretching on soreness in the current trial because stretching appeared to reduce soreness from the first reporting week when there was relatively little loss to follow-up, and the effects remained nearly constant thereafter.

A second risk of bias is that outcomes were self-reported and the participants were not blind. We did find that the effect of stretching on risk of bothersome soreness was associated with strength of belief of the effectiveness of stretching. This could reflect biased outcome reporting, or it could be that some of those who benefit from stretching perceived this benefit prior to the trial. At baseline about three times more participants agreed than disagreed that it is important to stretch when doing physical activity, so biases in reporting of outcomes, if they occurred, might have exaggerated effects of stretching. However there was no evidence of an interaction between effects of stretching on injury risk and strength of belief in effectiveness of stretching, and effects of stretching on risk of soreness were apparent even in those participants who did not believe in the effectiveness of stretching. The effect of stretching on risk of injury was not associated with strength of belief of the effectiveness of stretching.

Internet-based trials: An unusual feature of this trial is that it was conducted entirely by internet. Participants recruited themselves, were randomised by computer, and entered their own data, so researchers did not meet with participants at any stage. This approach to the conduct of clinical trials has the obvious disadvantage of relying on participants to report data accurately and consistently, and monitoring of compliance with the protocol is difficult. On the other hand, entirely internet-based trials provide a mechanism for recruiting large and diverse samples from non-clinical populations, which is otherwise difficult to do. For this reason we believe that entirely internet-based trials have many potential future applications, although we are aware of only a few prior trials that have used this approach.[13 14]

A second unusual feature of this trial is that it was undertaken in collaboration with a television programme in Norway and a radio programme in Australia. In addition, awareness of the trial was achieved through newspaper and magazine articles and the internet. Besides helping to recruit participants, collaboration with the media can help the public to learn about randomised trials and how to use results of randomised trials to inform decisions.

Applicability of the findings: Our trial stretches were similar to those often recommended before and after exercise.[15] However the protocol may have required participants to stretch more than they might otherwise. At baseline, 76.9% of participants who regularly stretched reported that they did so for a total (before and after exercise) of 10 minutes or less. While almost all participants partially complied with the stretch protocol, only 7.7% of participants in the stretch group always stretched for more than 10 minutes. These data suggest that many people may be reluctant to stretch for the durations commonly recommended and that recommended durations of stretch are unlikely to be achieved in practice. It is possible that larger effects would become apparent if participants stretched more, though we have no data to confirm that.

The trial investigated the effects of 12 weeks of stretching. Thus this trial can be used to make inferences about the short- and medium-term effects of stretching on risks of injury and soreness, but it is not clear if the results can be applied to longer-term effects of stretching.

The findings can be applied to community populations of physically active people but may not apply to professional athletes, who may be subject to different injury risks and may be able to stretch more intensely. We did not measure impacts on performance, which would be

an important outcome measure for competitive athletes. Likewise the findings may not apply to people who seek professional care for a specific injury. Some people with specific injuries may benefit from stretching, but this is yet to be demonstrated in randomised trials.

Some subgroups may benefit more from stretching than others; for example, greater benefits may be realised by people who are more compliant with the stretching protocol or engage in specific types of physical activity. However, given the design and power of this study to detect such differences, the current best estimates of the effects of stretching for any subgroup are our overall estimates.[16]

Implications for practice: For those who enjoy stretching or perceive it reduces soreness or increases looseness, the results of this trial support the decision to stretch. Those who do not enjoy stretching will need to balance a small reduction in soreness, a small increase in looseness and a probable reduction in muscle, ligament and tendon injuries against the effort and time it takes to stretch (see Summary of Findings Table).

Summary of findings table

Stretching before and after physical activity					
Patient or population: People who exercise regularly* **Intervention:** Stretching lower limb and trunk muscles before and after physical activity **Comparison:** No stretching					
	Illustrative comparative risks† (95% CI)				
Outcomes	**Assumed risk (non-stretching)**	**Corresponding risk (stretching)**	**Relative effect (95% CI)**	**Number of participants**	**Quality of evidence (GRADE)**
All injuries Follow-up: 12 weeks	562 per 1000	545 per 1000 (470 to 633)	HR 0.97 (0.84 to 1.13)	2,377 (1study)	⊕⊕⊕◯ Moderate§
Bothersome soreness Average experienced during a week	323 per 1000	246 per 1000 (218 to 281)	OR 0.69 (0.59 to 0.82)		
Muscle, ligament & tendon injuries Follow-up: 12 weeks	177 per 1000	133 per 1000 (104 to 171)	HR 0.75 (0.59 to 0.96)		
Severity of soreness (scale from 0 to 10)	Mean 2.9	Mean severity of soreness in the stretch group was 0.4 lower (0.2 to 0.5 lower)			
Looseness during activity (scale from 0 to 10)	Mean 3.3	Mean looseness during activity in the stretch group was 0.3 higher (0.1 to 0.4 higher)			
Looseness after activity (scale from 0 to 10)	Mean 3.7	Mean looseness after activity in the stretch group was 0.4 higher (0.3 to 0.6 higher)			
Time spent stretching (per session of physical activity)	None	7 minutes before and 7 minutes after activity			

CI: Confidence interval; HR: Hazard ratio; OR: Odds ratio.

*Participants in the study typically exercised 4 times per week (half exercised 3 or 4 times per week) and engaged in a variety of activities, including running (32%), training in a gym (31%), and cycling (14%).

†The basis for the **assumed risk** is what was observed in this study. The **corresponding risk** (and its 95% confidence interval) is based on the incidence rate or risk in the group that did not stretch and the relative effect of the intervention (and its 95% CI). Different assumed risks (i.e. a higher or lower risk without stretching) would be expected to result in different corresponding risks (assuming that the relative effect is the same).

‡All of the estimates of effect are based on this study, which is the only community-based study.

§We used the GRADE system to assess quality of evidence.[17] We downgraded the quality of evidence for all 6 outcomes from high to moderate because they were self-reported, data were incomplete, and the confidence intervals do not rule out either a potentially important effect (for all injuries) or a potentially unimportant effect (for other outcomes). **Moderate** quality indicates the true effect is likely to be close to the estimates shown here, but there is a possibility that they are substantially different.

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Contributorship: GJ and RH conceived the study. GJ, RH, AO, SF, ABarratt and KH designed the study, obtained approvals and funding, and managed the study. Oluf Jensen, Reidun Kværnbraaten, Qadeer Ahmad Alvi and Thomas Gauperaa (Norwegian Knowledge Centre for the Health Services) designed and maintained the web site. Dr Kathleen Skinner (Department of Public Health and Primary Care at the University of Oxford), Hilde Kari Nylund and Cheryl Carling (Norwegian Knowledge Centre for the Health Services) assisted with the study. JO-J and RH analysed the data. All authors contributed to interpretation of the data and revision of the final manuscript. RH wrote the first draft of the manuscript. GJ and RH are guarantors.

FIGURE LEGENDS

Figure 1. Completeness of data. Participants were asked to record the presence or absence of injuries and bothersome soreness each week provided they had not been injured earlier in the course of the study and (for soreness data) did not report they had not participated in physical activity that week. Completeness in each week was calculated as the number of valid reports divided by the number of randomised participants who had not been injured and (for soreness data) did not indicate they had not participated in physical activity.

Figure 2. Effect of stretching on A, survival from all lower limb and back injuries. B, risk of bothersome soreness. C, survival from specific injuries (injuries of muscle, ligament and tendon) of the lower limb and back.

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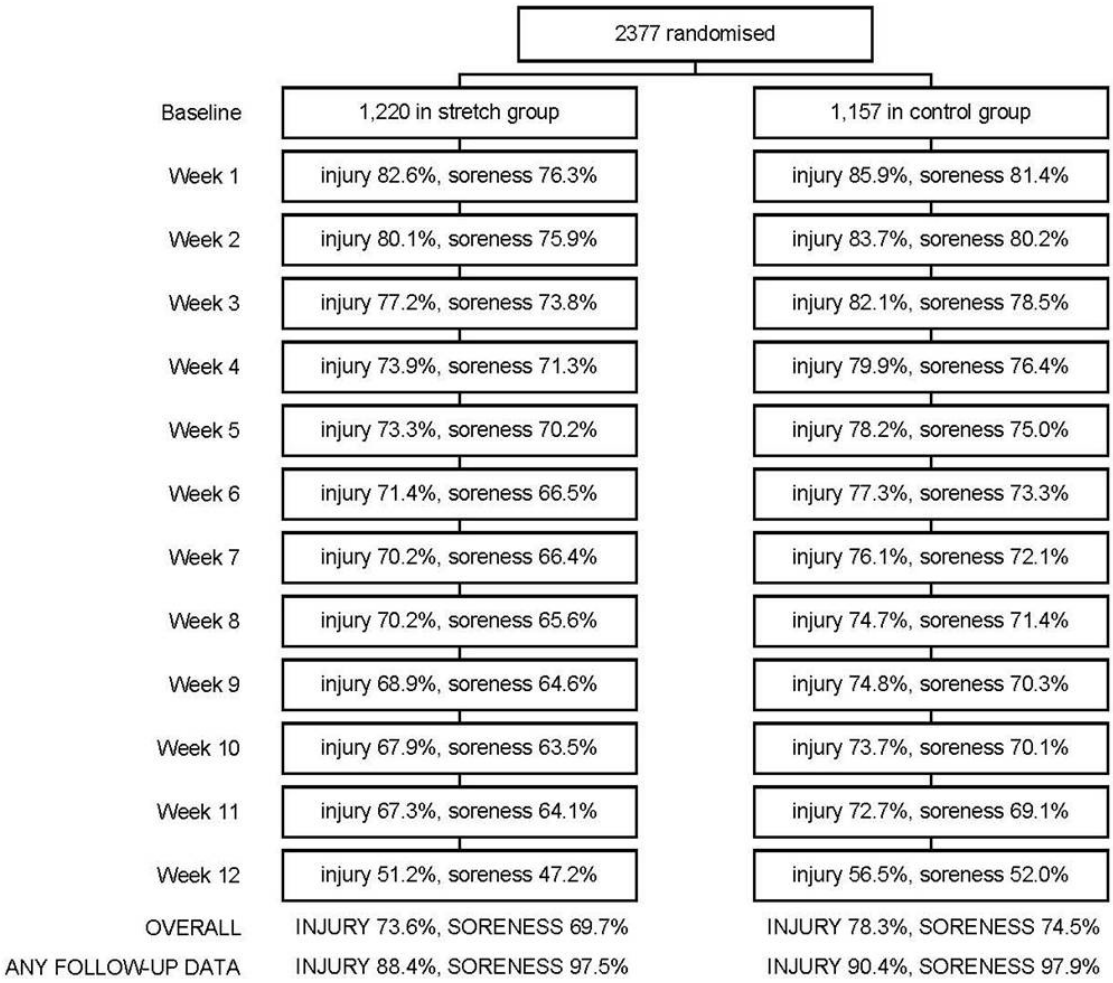

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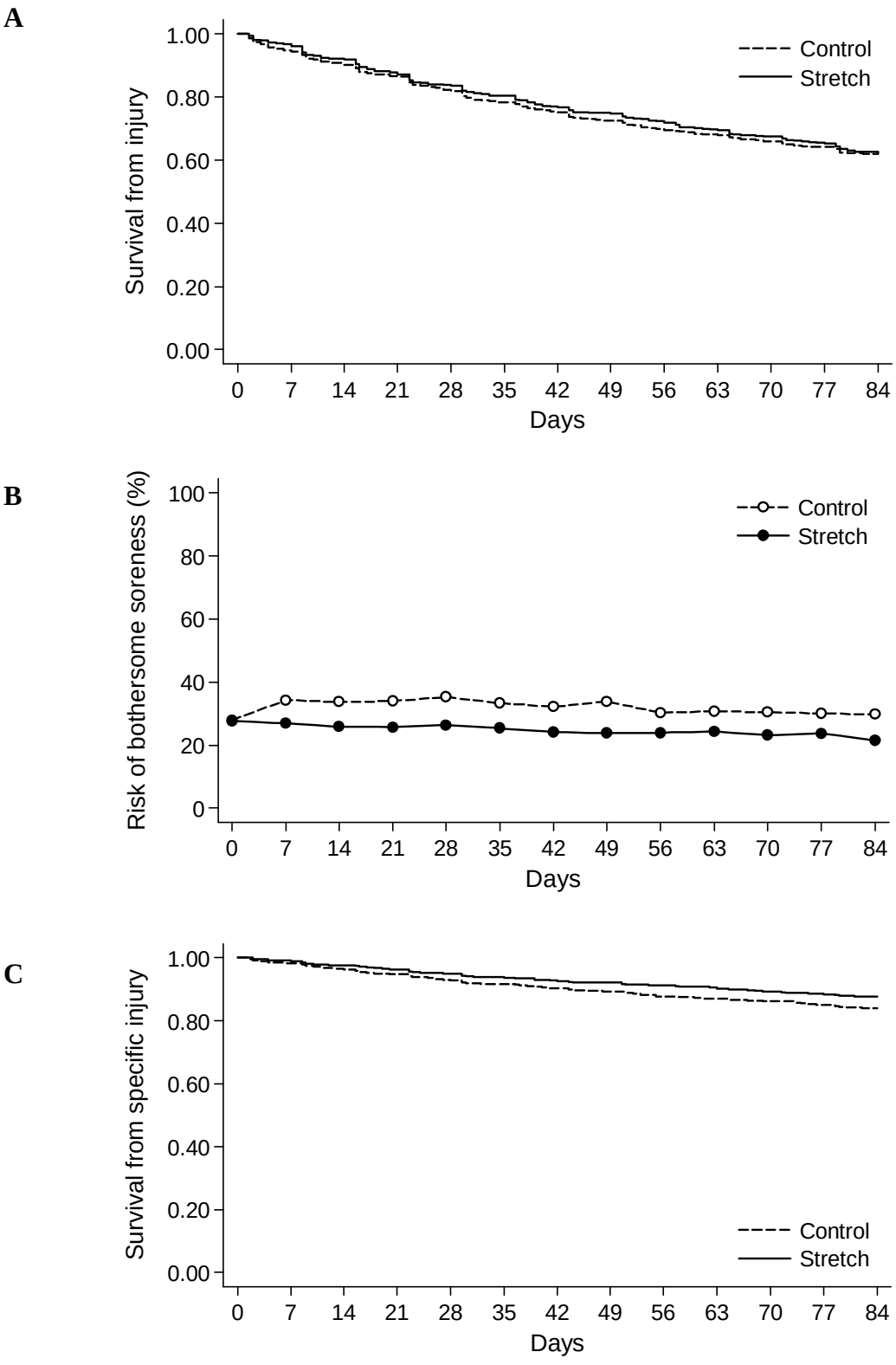

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