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ORIGINAL ARTICLE

# How effective and efficient are different exercise patterns in reducing back pain?

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ABSTRACT

BACKGROUND: Exercise is considered an effective intervention to relieve chronic back pain. However, it is still unknown whether specific exercise patterns vary in terms of their efficiency and effectiveness.
AIM: To investigate the differential health and economic effects of intensity, specificity and degree of subjective perceived physical exertion across five exercise patterns (endurance, gymnastics, fitness, back gymnastics, multimodal back exercise) in adults with back pain.
DESIGN: Longitudinal observational cohort study over a period of 24 months.
SETTING: Various non-therapeutic exercise facilities (*e.g.* outdoor, fitness centers, health insurance programs, sports clubs) across one federal state of Germany (Baden-Wuerttemberg).
POPULATION: Adults with back pain (N.=2,542, Mean =46.9 years, 66% females, graded chronic back pain [GCPS] 1=40.5%, GCPS 2=27.3%, GCPS 3=20.7%, GCPS 4=11.5%).
METHODS: Self-reported back pain (functional restrictions and pain = back pain function score, [BPFS]) and characteristics of exercising behavior (frequency, duration, type, physical exertion) were assessed at baseline and at 6, 12, 18 and 24 months. Direct medical costs for back disorders (international classification of diseases, dorsopathies: M40–M54) were compiled from health insurance records.
RESULTS: Moderate- to high-intensity exercise patterns were effective in reducing back pain, particularly at lower levels of subjective perceived physical exertion. At these intensity levels, multimodal back exercise (*i.e.* exercising the spine-stabilizing muscles specifically, ergonomic training) was 14.5 times more effective than non-back specific fitness exercise in reducing BPFS. The beneficial effects of both exercise types increased with the initial severity of back pain. However, only multimodal back exercise (moderate- to high-intensity/high back specificity) was associated with a significant decrease in direct medical costs for back pain.
CONCLUSIONS: Targeted exercise of the spine-stabilizing musculature at moderate to high intensities without maximum perceived exertion is effective and efficient in reducing back pain.
CLINICAL REHABILITATION IMPACT: The combination of high-intensity and high-specificity exercises yielded a significant reduction in medical costs. However, the intensities in terms of muscular load in endurance training and gymnastics may not be sufficient to reduce back pain effectively.

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KEY WORDS: Exercise; Physical exertion; Back pain; Cohort studies.

Back pain is responsible for most of the years lived with disability (YLD) worldwide and has a lifetime prevalence of over 70% in industrialized countries.[1, 2] The associated medical costs are estimated to amount up to 10% of the respective gross domestic product (GDP), underlining the claim that effective interventions not only alleviate pain for individuals but also bear considerable societal relevance.[3-6]

Physical activity has been shown to effectively reduce chronic back pain in a substantial number of studies and is consistently recommended for the management of nonspecific low back pain in clinical guidelines.[7-10] However, its mechanisms of action are not yet well understood.[7, 11-18] In physiological models, the pain-reducing effect is assumed to be related to neuronal adaptations associated with increases in trunk strength, stability and flexibility.[19] From a psychological-cognitive perspective, the combination of physical activity and pain reduction supposedly generates a self-reinforcing upward spiral of improvements in self-efficacy beliefs, self-management behaviors, psychosocial functioning and overall well-being.[8, 20] However, empirical results on the influence of type and intensity of exercise, as well as the subjective degree of perceived physical exertion (following Borg[21]assessment of physical exertion from any exertion at all up to maximum exertion on a scale from 0 to 10), are inconsistent,[8, 17-22] and empirical evidence on the question of whether a movement-induced reduction in back pain affects direct medical costs is rather fragmentary.[7, 9, 12, 23-25] Despite the double-digit number of systematic reviews published on the topic, there is no consensus on the relative effectiveness of different exercise patterns, and the question of which elements of an intervention are particularly decisive for the pain-reducing effect remains unanswered. Some authors, *e.g.* Haag *et al.*,[26] argue that "there is still no evidence that anyone specific approach is the most favorable," while others emphasize particular exercise characteristics; for example, Smeets *et al.*[18] concluded that "specific low back muscle strengthening exercises of sufficient intensity and frequency to fulfill the exercise physiology criteria show moderate evidence that they are more effective compared to less intensive exercises." This discrepancy seems to be affected by aspects such as the sample populations, experimental procedures and comparators in individual studies, which typically investigate a limited variety of exercise patterns in clinically homogenous sample populations. This approach has a rather paradoxical effect on the integration of evidence: systematic reviews/meta-analyses encounter high heterogeneity between samples and low comparability of exercise patterns.[27]

The primary aim of this investigation was to analyze the relative effectiveness and efficiency of different exercise patterns in reducing back pain. The structure of the German statutory health insurance system provides a convenient context for pragmatic research designs.[28] Alongside the implementation of a specific program for back pain prevention across one federal state of Germany, we conducted a longitudinal observational study in a sociodemographically diverse sample including a wide variety of exercise patterns, ranging from specific medically indicated training of the spine-stabilizing musculature to incidental leisure time exercises. In this paper, we address the following questions: first, how effective are different exercise patterns in reducing back pain? Second, does the degree of subjective perceived physical exertion influence the effects? Third, how do these parameters impact the economic perspective?

## Materials & Methods

### Study design and sample

The study was conducted as part of a nonrandomized multi-center evaluation trial on the effectiveness of a multimodal back exercise program compared to standard care for back pain, with assessments at baseline (t0) and after 6, 12, 18 and 24 months (t1, t2, t3, t4).[29] The inclusion criteria were a minimum age of 16 years and the presence of back pain (graded chronic pain status [GCPS]>0). The only exclusion criterion was a medical contraindication to physical exercise. The study was approved by the ethical review committee at the University of Greifswald (ID 33/08).

Out of 4888 contacted study participants, 2920 insurance holders agreed to take part in the evaluation study, of which 87% (N.=2542) were included in the analyses presented here. Reasons for exclusion were the absence of back pain (GCPS=0; N.=114), missing data on the back-pain function score ([BPFS]; N.=123) and missing data on medical costs (N.=141). Only the response rate for the questionnaires decreased with each assessment date (questionnaires data: t1 67%, t2 61%, t3 57%, t4 53%; cost data: t1-t4 100%) see Figure 1. The resulting data are nonexperimental data corresponding to the design of an observational cohort study. Participants are not grouped according to their type of exercise; each participant is included with his amount of training in each of the five categories (see outcome measures).

### Outcome measures

Back pain was assessed with the German version of the Chronic Pain Grade questionnaire,[30] a standardized self-report instrument, asking for pain intensity (3 items), pain-related functional impairment (3 items), the number of days on which pain was present (1 item) and impeded performance of routine daily activities (1 item). The original version recommends a categorization into five levels of GCPS:[30] no back pain, low pain intensity, high pain intensity, moderate functional impairment and severe functional impairment. However, the distinction between pain intensity and pain-related disability has been critically discussed.[31] A preliminary inspection of the data structure in our sample similarly revealed one single factor with an eigenvalue >1 by means of an exploratory factor analysis. Consequently, we combined the scores for pain intensity and functioning items for a mean total score, which ranged from 0 to 10 (Back Pain Function Score, BPFS).[32]

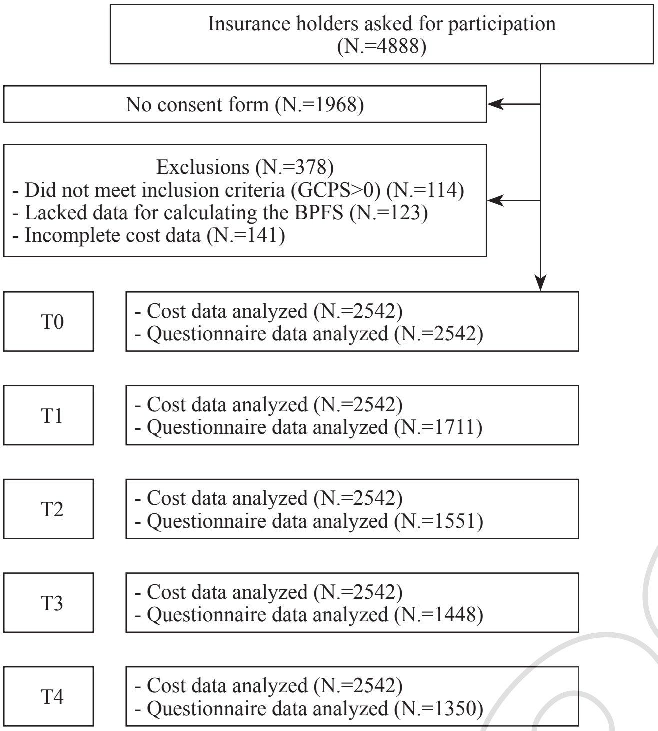


Figure 1.—Participant flowchart.

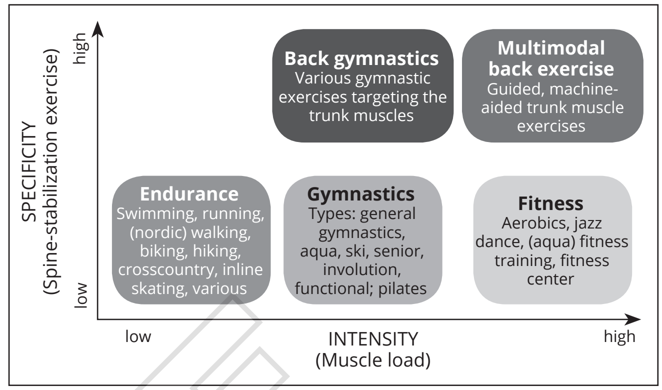


Figure 2.—Classification of exercise patterns.

Exercise patterns were assessed via a list of different exercises (*e.g.* walking, biking, and an additional blank space for other sports, such as Thai Bo or aqua fitness), on which participants indicated the frequencies, durations and subjective perceived physical exertion levels of their activities during the six months preceding each assessment (following Borg[21]), regardless of whether an activity was performed with the explicit aim of reducing back pain. The participants reported within the questionnaire their individually performed exercise pattern. They were not assigned to a specific exercise pattern.

The type of exercise was defined by a two-step rating process. A team of experts first developed a categorical scheme with the predefined criteria intensity (*i.e.* muscular load; ratings based on load and velocity of movements: exercise that uses a heavier load and/or faster velocity have a greater exercise intensity[33]) and specificity of exercise (*i.e.* spine-stabilizing exercise) (see Figure 2). Subsequently, each activity was assigned to one of the following categories:

• Endurance training: physical activities characterized by a low level of intensity and maintained over a prolonged period of time, often aimed at strengthening the cardiovascular system;

• Gymnastics: exercises to improve agility, coordination and strength across body parts at a low to moderate level of intensity;

• Fitness: exercises similar to those above mentioned at a moderate to high level of intensity;

• Back gymnastics: exercises specifically designed to improve the strength and mobility of the spine-stabilizing musculature at a low to moderate level of intensity;

• Multimodal back exercise (MMBE): exercises comparable to those above mentioned and performed on specialized exercise equipment at a moderate to high level of intensity and combined with ergonomic exercises for everyday motor activities (sitting, standing, lifting loads).[32]

Cost data were compiled directly from the insurance fund records, thus representing the actual net costs per participant attributable to back pain as coded in the International Classification of Diseases (ICD-10; Chapter XIII: Diseases of the musculoskeletal system and connective tissue, M40-M54). Costs include in- and outpatient acute care as well as rehabilitative treatment, statutory sick leave benefits, medically prescribed supplementary treatments (*e.g.* hydrotherapy, electrotherapeutic physiotherapy, and massages), and medication for pain relief as classified in the German Pharmaceutical Atlas (*e.g.* antiphlogistic, antirheumatics, and muscle relaxants).[34] Costs are expressed in euros and relate to a six-month time period preceding each assessment time point.

### Statistical analyses

Hierarchical linear models (HLMs) with random intercepts were chosen to analyze the effects of exercise patterns on health and economic outcomes. In order to analyze the longitudinal data resulting from observing the participants repeatedly over time, HLMs also known as linear mixed models or multilevel models, are applied. They are an extension of linear regression, which is more flexible in several aspects. Unlike in the case of linear regression model, which requires independent observations, HLMs allow dependent residuals and allows the modeling of the covariance structure of the data. While in repeated measurements ANCOVAs, another model to analyze longitudinal data, only participants, who are observed at all occasions, can be included in the model and participants with even a single missing value are discarded or their missing values have to be imputed, in HLMs one or more of the occasions for measurement may be missing for participants and there is no need to impute missing values. HLMs are the method of choice for longitudinal studies,[35] allowing the inclusion of cases with missing data. The nested data structure of the longitudinal data is addressed in two-level models, in which the repeated measures are viewed as a level (level 1) nested within the participants (level 2). Back pain (BPFS) and direct medical costs of back disorders were modelled as dependent variables. Participant characteristics and exercise patterns were included as independent variables: sex, age (centered), BPFS (t0), type of exercise, subjective perceived physical exertion (centered) and exercise volume for each assessment period (cumulated hours within a 6-month period). As the study is designed as an observational study, the participants reported within the questionnaire their individually performed exercise patterns and it can vary from measurement to measurement. They were not assigned to a specific exercise pattern. There are no groups defined by type of exercise (endurance exercise, etc.). The HLMs allow to estimate the effect of the amount of exercise patterns in the 5 categories on BPFS and medical costs, corrected for baseline measurements and demographic characteristics. We set the α-level at $P \leq 0.05$. The statistical analyses were performed with IBM SPSS 24.

## Results

In total, 2542 participants (66% females) were included in the analyses. Most participants had a middle level of education (80.5%), and their ages spanned a range of 17 to 83 years (Mean [M], Standard Deviation [SD], M=46.9; SD = 12.3) (see Table I). Mean direct medical costs in the six months preceding enrolment in the study was 204 € (SD=893 €). At baseline, average back pain ratings on the chronic pain grade questionnaire were M=5.0 (SD=2.0) for intensity and M=3.4 (SD=2.3) for impairment of functioning, corresponding to a BPFS score of M=4.2 (SD=2.0). For comparative purposes, the original scoring method is presented in Table I. Moreover, the values of specific pain items, functional items, employment status and sick days are included in Table I.

Across the study period, participants spent an average of 3193 minutes per 6-month period (123 minutes per week, SD=147) on exercises at a medium level of subjective perceived physical exertion (M=5.22; SD=1.97). Most of the total hours were spent on endurance training (67%), while moderate gymnastic exercises accounted for only 2% of the total exercise volume across participants (see Table II).

### Health effects

The relative effectiveness of different exercise patterns in reducing BPFS was examined in a two-level HLM with

Table I.—*Sample characteristics at baseline.*

| Age/sex | | |
|---|---|---|
| Age (M [SD]) | 46.9 | (12.3) |
| Females (%) | 66 | |
| Employment status (%) | | |
| Employed | 69.9 | |
| Pensioners | 15.9 | |
| Unemployed | 4.1 | |
| Family members without employment | 10.1 | |
| Sick days past 12 mths | | |
| Dorsopathies (M [SD]) | 6.9 | (24.3) |
| Overall (M [SD]) | 18.3 | (45.1) |
| Education (%) | | |
| Lower secondary (10 yrs.) | 17.3 | |
| Upper secondary (13 yrs.) | 63.2 | |
| Postsecondary (13+ yrs.) | 4.4 | |
| Tertiary (13+yrs.) | 6.4 | |
| Back pain (Chronic Pain Grade Questionnaire) | | |
| Pain intensity (0-10) (M [SD]) | 5 | (2) |
| Pain right now | 3.9 | (2.4) |
| Pain as bad as could be | 6.4 | (2.4) |
| Average pain | 4.6 | (2.2) |
| Impairment of functioning (0-10) (M [SD]) | 3.4 | (2.3) |
| Daily activities | 3.4 | (2.4) |
| Recreational, social and family activities | 3.4 | (2.5) |
| Work (including housework) | 3.5 | (2.5) |
| BPFS (0-10) (M [SD]) | 4.2 | (2) |
| Days in pain past 6 months (M [SD]) | 76.1 | (64.5) |
| Days with pain-related disability past 6 mths (M [SD]) | 17.9 | (37.4) |
| GCPS 1 (%) | 40.5 | |
| GCPS 2 (%) | 27.3 | |
| GCPS 3 (%) | 20.7 | |
| GCPS 4 (%) | 11.5 | |

M= Mean, SD= Standard deviation
Graded chronic pain status 1= low pain intensity
Graded chronic pain status 2= high pain intensity
Graded chronic pain status 3= moderate functional impairment
Graded chronic pain status 4= severe functional impairment

TABLE II.—*Exercise volume per category and 6-month period.*

| Category | Time total (minutes) | SD | % |
|---|---|---|---|
| Endurance | 2,131 | 3,024 | 67 |
| Fitness | 419 | 1,067 | 13 |
| Back gymnastics | 328 | 695 | 10 |
| Multimodal back exercise | 247 | 307 | 8 |
| Gymnastics | 69 | 236 | 2 |
| Total | 3,193 | 3,831 | 100 |

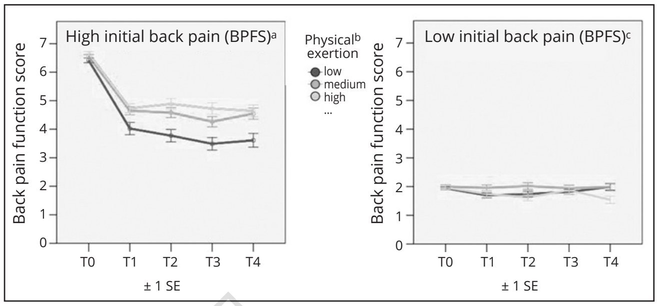


Figure 3.—Effectiveness for the upper and lower tertiles of subjective perceived physical exertion. [a]Left-hand side: participants with high initial back pain ($BPFS_{t0}$>5.2); [b]tertiles of subjective perceived physical exertion; low: ≤4.6, 4.6< medium ≤6.0, high >6.0; [c]right-hand side: participants with low initial back pain ($BPFS_{t0}$<3.3).

initial back pain, age and sex as control variables (see Table III). Overall, the model explained 32% of the variance in self-reported pain (BPFS).

Only exercise categories requiring moderate to high levels of intensity/muscular load yielded significant pain-reducing effects (*i.e.* $ß_{MMBE}$=-0.029, *t*=-30.0, P<0.001; $ß_{fitness}$=-0.002, *t*=-5.1, P<0.001) (see Table III). The effect was stronger for MMBE than for fitness by a factor of 14.5 ($β_{MMBE}/β_{fitness}$). In other words, an average participant exercising approximately 2 hrs per week for half a year (50 hrs) would experience a pain reduction of 1.43 points in the BPFS ($β_{MMBE}$* 50 hrs) with MMBE and a pain reduction of 0.1 points with fitness exercises ($β_{fitness}$* 50 hrs). Exercising at higher levels of subjective perceived exertion significantly increased back pain ($ß_{exertion}$=0.08, *t*=8.23, P<0.001). Given the average degree of exertion (M=5.22; SD=1.97), an increase/decrease by one standard deviation would be associated with an increase/decrease in back pain of 0.16 points in the BPFS ($SD_{exertion}$* $ß_{exertion}$). The effects of MMBE, fitness and physical exertion increased with the level of initial back pain (see Table III).

Among the participant baseline characteristics, initial back pain and the age of the participants significantly moderated the effects of the exercise patterns. A higher level of initial pain by one point on the BPFS (rating scale 0-10) augmented the pain-reducing effect of moderate- to high-intensity exercises and exacerbated the disadvantage of exercising at high physical exertion levels by a factor of 0.8 (see also Figure 3). The effect of age was less pronounced than the effect of initial back pain, lowering the pain-reducing effects for older participants by 0.1 points/ BPFS per 10 years in age difference (see Table III).

### Economic effects

In the two-level HLM on economic effects, only MMBE was significantly associated with a cost reduction ($ß_{MMBE}$=-1.72, *t*=-3.6, P=<0.001). The effect of cost reduction through MMBE increased slightly with the level of back pain (ßBPFS t0*MMBE=-0.66, *t*=-2.7, P=0.008) (Table IV). Thus, an average exercise volume reduced medical costs by 86 € ($ß_{MMBE}$* 50 hrs), which is a reduction of 42% compared to the baseline costs ($m_{t0}$ =204 €). Initial back pain and sex significantly moderated this ef-

TABLE III.—*Results from the hierarchical linear model for BPFS.*

| | ß-coefficient | SE | t-value | P | Confidence interval 95% | |
|---|---|---|---|---|---|---|
| | | | | | Lower bound | Upper bound |
| Constant term | 3.91803 | 0.03469 | 112.946 | <0.001 | 3.85002 | 3.98605 |
| Age | 0.01065 | 0.00202 | 5.261 | <0.001 | 0.00668 | 0.01462 |
| Sex (male=1) | -0.00003 | 0.05133 | -0.001 | 0.999 | -0.10069 | 0.10062 |
| Physical exertion | 0.07985 | 0.00970 | 8.231 | <0.001 | 0.06083 | 0.09887 |
| Multimodal back exercise | -0.02866 | 0.00095 | -30.047 | <0.001 | -0.03053 | -0.02679 |
| Endurance | -0.00025 | 0.00014 | -1.877 | 0.061 | -0.00052 | 0.00001 |
| Fitness | -0.00197 | 0.00039 | -5.109 | <0.001 | -0.00273 | -0.00122 |
| Gymnastics | -0.00058 | 0.00146 | -0.398 | 0.691 | -0.00343 | 0.00227 |
| Back gymnastics | 0.00065 | 0.00062 | 1.048 | 0.295 | -0.00057 | 0.00187 |
| BPFS t0 | 0.83987 | 0.01425 | 58.934 | <0.001 | 0.81193 | 0.86781 |
| BPFS t0*physical exertion | 0.02631 | 0.00465 | 5.661 | <0.001 | 0.01720 | 0.03542 |
| BPFS t0*MMBE | -0.00918 | 0.00050 | -18.422 | <0.001 | -0.01016 | -0.00820 |
| BPFS t0*fitness | -0.00058 | 0.00016 | -3.631 | <0.001 | -0.00089 | -0.00026 |

TABLE IV.—*Results from the hierarchical linear model for direct medical costs for back disorders.*

| | ß-coefficient | SE | t-value | P | Confidence interval 95% | |
|---|---|---|---|---|---|---|
| | | | | | Lower bound | Upper bound |
| Constant term | 161.10 | 16.19 | 9.949 | <0.001 | 129.35 | 192.85 |
| Age | 0.29 | 0.86 | 0.331 | 0.741 | -1.41 | 1.98 |
| Sex (male=1) | 71.64 | 21.73 | 3.297 | 0.001 | 29.02 | 114.25 |
| Physical exertion | -7.71 | 4.92 | -1.565 | 0.118 | -17.36 | 1.95 |
| Multimodal back exercise | -1.72 | 0.48 | -3.602 | <0.001 | -2.65 | -0.78 |
| Endurance | -0.05 | 0.06 | -0.839 | 0.402 | -0.18 | 0.07 |
| Fitness | 0.03 | 0.18 | 0.186 | 0.852 | -0.32 | 0.39 |
| Gymnastics | 0.35 | 0.67 | 0.521 | 0.602 | -0.97 | 1.67 |
| Back gymnastics | -0.05 | 0.28 | -0.159 | 0.873 | -0.60 | 0.51 |
| BPFS t0 | 58.24 | 6.54 | 8.903 | <0.001 | 45.41 | 71.07 |
| BPFS t0*physical exertion | -2.29 | 2.35 | -0.973 | 0.331 | -6.90 | 2.32 |
| BPFS t0*MMBE | -0.66 | 0.25 | -2.661 | 0.008 | -0.60 | 0.51 |
| BPFS t0*fitness | -0.09 | 0.07 | -1.208 | 0.227 | -0.60 | 0.51 |

fect. Cost reduction was more pronounced in male participants than in female participants ($ß_{sex}$=71.6, *t*= 3.3, P=0.001) and in those with higher levels of initial back pain than those with lower levels of initial back pain ($ß_{B-PFSt0}$= 58.2, *t*=8.9, P<0.001). Overall, the model explained 33% of the variance in direct medical costs.

## Discussion

The present study examined how intensity, specificity, and subjective perceived physical exertion influence the effects of exercise on pain reduction and medical costs in adults with back pain, based on data from a 24-month observational cohort study with a large, heterogeneous community sample. The results indicate that only exercise patterns with a moderate to high intensity in terms of muscular load significantly reduced pain, *i.e.* fitness training and MMBE, whereas exercise patterns requiring less muscular effort, such as endurance training, gymnastics and back gymnastics, did not yield significant effects. The effectiveness of exercises with moderate to high intensities was multiplied by a factor of 14.5 when the spine-stabilizing musculature was targeted. Only this combination of intensity and specificity, as applied in the MMBE program, significantly reduced direct medical costs for back disorders. The analyses were controlled for sex, age and initial back pain.

These results add to the empirical evidence that a minimum threshold of exercise intensity must be exceeded to reduce back pain effectively.[12, 36-39] From a physiological perspective, the relative advantage of specific training is a logical consequence of this effect; exercises of high intensity elicit large muscle activations, which in turn stimulate the neural and physiological adaptations associated with improved functionality and strength of the targeted musculature (cross-sectional enlargement).[40] Strengthening the spine-stabilizing musculature may thus counteract any disturbances in muscle activation patterns, weakness and fatigability inducing and/or resulting from the experience of back pain.[12, 41-44]

An unexpected finding was that although exercising at a higher intensity was more effective, higher subjective perceived physical exertion levels during the exercise sessions intensified back pain. This ostensible contradiction might be explained by a combination of physiological and psychological effects. The physiological overload aligned with maximum exertion not only harbors the risk of damage but also leads to sensations that might be perceived as gratifying in the context of strength training but often fuel the fear of pain in rehabilitation patients.[45] In implementing an exercise regimen for preventive or clinical purposes, the general aim should be attaining optimal rather than maximum results.[46] For individuals with back pain in particular, the experience of painless physical activity is assumed to positively change beliefs, attitudes, and coping mechanisms.[47-49] In addition, exercising with high levels of intensity might enable the feeling of having mastered a challenge and thus reduce avoidance behaviors in the future. However, not only fear avoidance beliefs lead to physical inactivity. There are further internal and external barriers for physical activity. The most common internal barriers for middle-aged people were “too tired,” “already active enough,” “do not know how to do it” and “too lazy,” while those for elderly people were “too tired,” “lack of motivation” and “already active enough”.[50] However, compared to the fear avoidance beliefs these barriers might be of minor relevance for back pain patients.

In the cost-efficient analysis of our data, only the MMBE program yielded a significant reduction in direct medical costs for back disorders. On the other hand, fitness training, *i.e.* exercises of high intensity but low specificity, significantly reduced back pain but did not reduce costs. To our knowledge, none of the previous studies compare the efficiency of different exercise patterns.[24, 25] The most recent meta-analysis cautiously concludes that "there is inconsistent and heterogeneous evidence, although, exercise therapy may be a cost-effective intervention compared with usual care for chronic low back pain " (page 180).[24, 25] Our data potentially indicate that a critical threshold for health effects must be crossed before economic effects can be achieved.[51]

### Limitations of the study

The main source of limitation is the focus of the original trial, which evaluated the multimodal back exercise program compared with standard back pain care.[29] The sample characteristics limit the external validity of the study, because the population was of insurance holders.

It has advantages and disadvantages to observe study participants' exercising behavior under almost natural conditions, which means specific combinations of exercise patterns per participant. The disadvantage is, that this kind of model does not enable pointing out exercise effects of single times of measurement. This is done frequently in comparison of groups. The advantage of the HLM is the consideration of all exercise patterns and their effects on the BPFS under natural conditions. Thus, we can show the effect of a specific exercise pattern per hour of exercise. In our study we only considered the first two domains out of the six core domains:[52] 1) pain; 2) physical functioning; 3) emotional functioning; 4) participant ratings of improvement and satisfaction with treatment; 5) symptoms and adverse events; and 6) participant disposition. Accordingly, the interpretation of results limited.

While the intensity of the multimodal back exercises was based on one-repetition maximum [% 1 RM] on different machine-aided trunk exercises, expert ratings were used to categorize the other exercise pattern categories. Thus, no objective statements regarding the intensity and specificity of the different categories can be provided. Particularly with regard to policy implications of the cost-efficacy analysis, our results should be replicated with a stronger monitoring of the other exercise patterns to rule out potential biases in these analyses, *e.g.* scheduling, guidance or motivational support.

The relationship between exercise intensity and subjective perceived physical exertion in our results emphasizes an important topic for future research. In general, a primarily linear relationship between subjective perceived physical exertion and objective physical load (*i.e.* intensity of exercise) is assumed.[21] However, this relationship has been shown to be influenced by psychological, social and contextual factors, all of which might influence the perception of physical exertion in individuals with chronic back pain.[53, 54] Interestingly, in a parallel analysis of the data presented in this article, the number of training sessions was more relevant for back pain reduction than were increases in physical performance.[32] A more comprehensive understanding of the complex interaction between physiological and psychological mechanisms may be valuable in improving exercise interventions for back pain. For example, it may be conceivable to give corrective feedback and/or adjust exercises based on combined information about subjective perceived physical exertion and objective load, thus increasing the effectiveness of exercises.

## Conclusions

In conclusion, this study indicates that a certain intensity of exercise is an essential prerequisite for back pain reduction, which is most effectively achieved when the spine-stabilizing musculature is targeted and the level of subjective perceived physical exertion is not exceedingly high. The intensities in terms of muscular load in endurance training and gymnastics may not be sufficient to reduce back pain effectively. Only the combination of high-intensity and high-specificity exercises yielded a significant reduction in medical costs. More research is needed to disentangle the physiological and psychological mechanisms of action involved in these differential effects of exercise patterns.

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