Abstract
This chapter examines two stress-related characteristics of exercise in more detail: (a) the relationship between exercise and perceived stress and (b) the stress-buffering effect of exercise. Cross-sectional, longitudinal and experimental evidence are presented and analysed. Findings support the assumption that engagement in exercise can lead to reductions in perceived stress levels but that at the same time higher perceived stress levels might also cause decreases in exercise behaviour. Furthermore, empirical evidence supports the assumption that exercise and fitness buffer detrimental stress effects on mental and physical health. However, many questions still remain unanswered.

Keywords
Exercise • Health • Stress • Stress buffer • RCT

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1 Introduction

It has long been recognized that physical exercise, health and stress are closely interrelated (de Geus and Stubbe 2007; Raglin and Wilson 2012). The aim of this chapter is to shed light on two particular links between those variables: First, the relationship between exercise and perceived stress will be analysed and discussed in Sect. 2; second, an analysis and discussion of the so-called stress buffer effect of exercise will be presented in Sect. 3 (see Fig. 1 for a visual representation of the two topics). Both sections focus on non-clinical populations and contain three subsections in which cross-sectional, longitudinal and experimental evidence on each topic will be summarised. The goal of each subsection is to illustrate the broad variety of study designs, samples, methods and measurements used to enable readers to form their own view. The text tries to summarise main findings in the field of research but it is no systematic literature review, thus, it does not provide an overview of all studies published in this area. A particular focus of the present chapter lies on experimental results which will be depicted and analysed in more detail in Sects. 2.3 and 3.3. Lastly, based on the presented empirical evidence, a conclusion on the stress regulating effects of physical exercise will be provided in the final Sect. 4.

It should be noted that only the effects of regular (chronic) exercise are of interest in this chapter; studies investigating single exercise sessions will not be included. The text will not strictly differentiate between the terms physical activity and exercise but usually the term exercise will be used to describe more vigorous and planned activities (Caspersen et al. 1985). Furthermore, it is important to keep in mind that chronic exercise and physical fitness are two distinct but closely related concepts (Brandes 2012). Studies presented in the following sections will suggest that both variables play a stress-regulative role but it is often hard to separate the variables’ effects, especially if only one variable is being examined. Lastly, this chapter will follow the assumptions of the Transactional Stress Theory which regards perceived stress as the subjective product of a complex transactional phenomenon between the person and the environment (Lazarus and Folkman 1984).

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**Fig. 1** Visual representation of the topics discussed in this chapter

**Section 2:** Direct relationship between stress and exercise

**Section 3:** Exercise as moderator of the stress-health relationship
2 The Relationship Between Exercise and Stress

This section will examine the relationship between the two variables exercise and stress. If exercise and stress are found to be related to each other, the relationship can be positive (i.e., higher levels of exercise are associated with higher ratings of stress/lower levels of exercise are associated with lower ratings of stress) or negative (i.e., higher levels of exercise are associated with lower ratings of stress/lower levels of exercise are associated with higher ratings of stress). Looking at causality, there are three ways how a relationship between exercise and stress can originate (not considering any moderating or mediating variables): (a) exercise has an effect on stress; (b) stress has an effect on exercise; (c) exercise and stress bidirectionally affect each other. In the following, the type of the relationship (none, positive or negative) and the causal direction of the relationship (options a-c above) will be investigated. First, a summary of cross-sectional study findings will illustrate the size and the type of the relationship which is usually found between exercise and stress (Sect. 2.1). Second, an overview of longitudinal findings will provide first insights into the direction of the relationship between the two variables (Sect. 2.2). Lastly, a summary of experimental findings will provide evidence regarding the causal relationships between exercise and stress (Sect. 2.3).

It is important to note that this section will solely examine the relationship between exercise and perceived stress and that the term stress will be used interchangeably with the term perceived stress. It is clear that stressors, i.e., the demands or stressful events causing stress reactions, also play a key role in the stress process and thus, their links with exercise are likewise of interest. However, the relationship between physical exercise and perceived stress is of greater interest because of its possible bidirectionality – both variables are able to influence each other; this does not hold true for the relationship between physical exercise and stressors (e.g., critical life events). The majority of studies examining the relationship between stressors and exercise focus on negative life events, daily hassles, and occupational stressors, but it is most unlikely that exercise can affect those stressors (e.g., death of a spouse; unfriendly neighbours; too little control at work). For further information on the relationship between stressors and exercise see for instance Stults-Kolehmainen and Sinha (2014) or Fuchs and Klaperski (2017).

2.1 Exercise and Stress: Cross-Sectional Evidence

Numerous larger and smaller cross-sectional studies have examined the relationship between exercise and stress. Exercise and stress can be negatively or positively correlated, or they can be unrelated. There are many different ways in which the relationship between exercise and stress can be examined and methods and findings differ between different cross-sectional study types. In the following, some key findings of large-scale population studies and surveys with medium to small sample sizes will be summarised to reflect the diversity of study methods and findings.
**Population Studies**  Typically, large-scale population studies survey representative population samples and provide information about Relative Risks (RR) or Odd Ratios (OR). These describe risks/odds of an outcome (e.g., physical inactivity) in an exposed group (e.g., individuals reporting high stress levels) compared with a non-exposed group (e.g., individuals reporting low stress levels). The odd ratio approximates the relative risk when the probabilities of an outcome are rather small but it is less intuitive to interpret than a relative risk (Peat et al. 2009, pp. 43–46).¹ In an early large-scale population study with over 32,000 working adults from the USA, Aldana et al. (1996) examined the relative risks for experiencing moderate and high levels of perceived stress in less versus more active participants. They found that participants who had an average energy expenditure above 3.0 kcal/kg/day – which equals about one hour of brisk walking or 20 min of jogging per day – experienced stress less often than participants who indicated a lower energy expenditure. Compared to the less active group the relative risk to experience high stress was 0.62 (CI = 0.55–0.71) in the more active group, which means the prevalence of high stress was almost one third lower in more active participants (Aldana et al. 1996). A recent population survey found a very similar result for more than 45,000 older adults (50–79 years) from Canada (Azagba and Sharaf 2014). The authors applied a similar technique as Aldana et al. (1996) to divide their sample into an inactive and an active group, but used an average energy expenditure of 1.5 kcal/kg/day as splitting point. Participants who reported high perceived stress levels were more likely to be physically inactive (adjusted OR = 1.41 [CI = 1.32–1.66]) than those who reported to experience no stress at all. These results were also supported by Schnohr et al. (2005) who found in a sample of more than 12,000 Danish participants a decrease in high levels of stress with increasing physical activity levels. Various other population studies from other countries using other samples found the same negative relationship between physical activity and stress (e.g., Ahola et al. 2012; Kouvonen et al. 2005; Nielsen et al. 2008; Rosengren et al. 1991; Wemme and Rosvall 2005).

Conversely, there was also a study with more than 17,600 Canadians which did not find a negative relationship between exercise and stress; on the contrary, using structural equation modelling, Iwasaki et al. (2001) found a positive relationship between the two variables with higher levels of chronic stress being associated with greater participation in physical activities. However, their stress measure seemed to focus on chronic stressors, instead of perceived stress, making an interpretation difficult. Even more unexpected results emerged from an analysis of more than 65,000 answers to a nationwide US American survey (Zuzanek et al. 1998): While the relationship between perceived physical activity (i.e., whether subjects felt more or less active than others) and perceived stress showed a weak negative correlation,

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¹Example: The Relative Risk is calculated by dividing the probability of physical inactivity levels in a highly stressed group (e.g., 50 in 100) by the probability of physical inactivity in a non-stressed group (e.g., 10 in 50) – RR = (50/100)/(10/50) = 2.5. The Odd Ratio is calculated by dividing the odds for physical inactivity in a highly stressed group (50 inactive/50 active) through the odds for physical inactivity in a non-stressed group (10 inactive/40 active) – OR = (50/50)/(10/40) = 4.
actual participation in exercise (based on self-reports on actual exercise participation) correlated positively with perceived stress levels.

*Cross-Sectional Surveys* Surveys with smaller sample sizes than in population-based studies often examined the relationship between exercise and stress by comparing mean stress levels for different exercise groups or by using correlation or multiple regression analyses. For instance, Lovell et al. (2015) examined 3601 Australian and New Zealand mothers with a child aged 5 years or younger and compared perceived stress levels of women who did not exercise with women who exercised once a week, women who exercised three or four times a week and women who exercised daily. Statistical analyses revealed that the inactive group had significantly higher stress levels than the once per week exercise group, while the latter group reported significantly higher stress levels than women who exercised three or four times a week or daily (all \( p < 0.05 \)). This shows that even rather small amounts of exercise are already negatively associated with perceived stress and that differences seem to be greater for higher levels of exercise. However, effect sizes in the study from Lovell et al. (2015) were rather small with \( d = 0.24 \) being the largest effect for the difference found between sedentary women and women who exercised three to four times per week. Using a very different sample, namely 179 American Indians and Alaska Natives, and a 3-day pedometer assessment of physical activity, Bersamin and colleagues (2014) found the same significant negative relationship between perceived stress and *objectively assessed* physical activity: A single multivariate linear regression revealed that more steps per day were associated with lower perceived stress levels (\( b = 0.16, t = 2.23, p = 0.03 \)). Another study recently corroborated these findings for objectively assessed vigorous-intensity exercise in undergraduate students (Gerber et al. 2014). Again, several other studies examining other samples support this negative relationship between perceived stress and exercise further (e.g., Craike et al. 2010; Gerber et al. 2015; Heslop et al. 2001; Jonsdottir et al. 2010; Laugero et al. 2011; Lutz et al. 2007; Ng and Jeffery 2003; Nguyen-Michel et al. 2006). However, a few studies did not find a negative relationship between perceived stress and exercise (e.g., Gerber et al. 2010; Hubbs et al. 2012; Wu and Porell 2000; Yin et al. 2005). Interestingly, even though Gerber and colleagues (2010) did not find significant correlations between perceived stress and moderate or vigorous exercise in their sample of 533 Swiss police and emergency response service officers, they did find a significant relationship between perceived stress and perceived fitness \( (r = -0.12, p < 0.001) \). This result indicated a stronger relationship between perceived stress and fitness than between perceived stress and exercise (Gerber et al. 2010).

All in all, there is a clear majority of studies which found a small to moderate negative relationship between exercise and perceived stress. Often, effects were stronger for participants who engaged in more vigorous exercise or who were active more often. However, some studies also found no or a positive relationship and some findings suggest that correlations differ for different indicators of physical exercise. Even though it is tempting to presume that exercise and perceived stress are negatively affecting each other, no causal conclusions can be drawn at this stage.
The following section will examine further whether and how exercise might act upon stress and vice versa by drawing on longitudinal evidence.

### 2.2 Exercise and Stress: Longitudinal Evidence

In a narrow sense, longitudinal observational studies cannot be used to test causality, but they can provide first tentative insights into the cause of the relationship between exercise and stress. This is achieved by observing exercise and perceived stress levels over time; some studies monitored participants over several weeks (e.g., by asking them to keep a diary or to complete weekly questionnaires), whereas others surveyed the same population several times with a time interval of several weeks or months. Data were analysed by numerous different methods, ranging from the assessment of relative risks and odd ratios, to analyses of cross-lagged relationships by means of structural equation modelling. The following text will first summarise studies which support the assumption that exercise affects stress levels; second, an overview of studies supporting the opposite relationship will be presented.

**Impact of Exercise on Stress** There are several longitudinal studies which support the assumption that exercise affects stress levels and all found a negative relationship, i.e. they all support the notion that exercise reduces perceived stress levels (Jonsdottir et al. 2010; Nelson et al. 2008; Schnohr et al. 2005). For instance, Jonsdottir and colleagues (2010) examined exercise and stress levels of more than 3000 Swedish employees in 2004 and in a follow-up in 2006. Their analyses indicated that the relative risk of experiencing high stress at time of the follow-up was lower for participants who reported higher activity levels at baseline, with the lowest relative risk of 0.40 for moderately to vigorously active participants. Similarly, in addition to their previously described cross-sectional analysis, Schnohr et al. (2005) investigated how a change of activity levels within a 5-year period was associated with perceived stress. The authors found that a change from a sedentary to a physically active lifestyle was associated with a lower odd ratio for high stress levels (OR = 0.48) while the opposite was true for participants who became sedentary (OR = 0.64, compared to OR = 0.29 for people who stayed active). However, two studies which used structural equation modelling did not find any significant effects of exercise on perceived stress levels at a follow-up measurement point (Gerber et al. 2015; Lutz et al. 2007; see also below).

**Impact of Stress on Exercise** Several studies tested the assumption that stress affects exercise levels (for a more detailed overview see Stults-Kolehmainen and Sinha 2014). Results are rather heterogeneous with some studies supporting (Lutz et al. 2007, 2010; Stetson et al. 1997) and some refuting (e.g., Gerber et al. 2015; Griffin et al. 1993; Steptoe et al. 1998) the assumption. Stetson and colleagues (1997), who investigated a smaller sample of 70 female US Americans, found only partial support for an influence of perceived stress on exercise: In high-stress weeks participants tended to omit more planned exercise sessions and they enjoyed exercise sessions...
significantly less than in low-stress weeks. However, frequency and duration of exercise sessions did not significantly differ between weeks with low and high perceived stress levels. Applying a similar weekly diary report method in a sample of 44 nurses and teachers, Steptoe et al. (1998) did not find that any changes in perceived stress were significantly associated with changes in exercise frequency or duration. On the contrary, a study of 203 US blue-collar workers showed unambiguous support for the assumption that stress reduces exercise levels (Lutz et al. 2007): Structural equation modelling showed a significant cross-lagged relationship between stress at the first measurement point and strenuous exercise 2 months later, while there was no comparable cross-lagged association between exercise and stress. However, in a similar recent study from Gerber et al. (2015), surveying 580 physically active Swiss vocational students twice with a 10 months interval between surveys, significant associations were found for neither of the two described cross-lagged paths between perceived stress and vigorous exercise.

**Conclusion** Based on this brief overview of longitudinal findings, it can be stated that on the one hand exercise might be able to reduce perceived stress levels and on the other hand high perceived stress might also cause reductions in exercise participation. While more certain causal conclusions can only be derived from experimental studies, another longitudinal study provides further insights into the complexity of the relationship between exercise and stress and indicates that conflicting findings might be partly caused by individual differences in the consistency of exercise behaviour. In their study, Lutz et al. (2010) monitored stress and exercise levels in a sample of 95 female students for 6 weeks and they related their findings to the stages of change proposed by the Transtheoretical Model (TTM; Prochaska and Velicer 1997). Results showed that for women at the exercise maintenance stage an increase in perceived stress levels was not associated with a change in the number of days of exercise per week, whereas for women at all other stages a negative association was found. Women who were classified as being at the maintenance stage even reported higher amounts of exercise per day when experiencing higher stress levels while women at other stages showed decreases in their self-reported daily amounts of exercise. Therefore, individual differences might trigger opposing effects which may neutralise each other so that variables appear to be unrelated.

Yet, overall the presented correlational evidence does not show a zero-correlation but a negative association between the two investigated variables. The results from Lutz and colleagues (2010) are valuable as they emphasise the importance of making exercise a habit, which is maintained independently of stress levels. Persons who then perceive stress reduction as one of the benefits of exercise will not significantly

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2In line with the TTM the study differentiated between five primary stages of exercise behaviour and used the following classification: 1. Precontemplation (no intention to exercise within next 6 months); 2. Contemplation (thinking about starting to exercise within next 6 months); 3. Preparation (exercising less than 3x/week for 20 min or more each time); 4. Action (exercising regularly, at least 3x/week for at least 20 min, but for less than 6 months); 5. Maintenance (exercising regularly, at least 3x/week for at least 20 min, for at least 6 months).
reduce their exercise levels when facing higher levels of stress but will actively use it as coping strategy (Cairney et al. 2014).

2.3 Exercise and Stress: Experimental Evidence

Causal explanations can only be derived from experimental studies. However, a problem is being encountered when examining the relationship between exercise and perceived stress: Correlational evidence has indicated that exercise may reduce perceived stress just as higher stress may lead to reductions in exercise levels – while it is unproblematic to experimentally test the influence of exercise on stress, experimental studies on the influence of stress on exercise levels would be difficult to conduct and hard to ethically justify. Thus, hardly any experimental studies examining the effects of stress on exercise participation exist. Consequently, this section will focus on the effects of exercise on stress levels, summarising potential effects of stress on exercise participation only briefly in the next subsection.

2.3.1 Stress Reduces Exercise Levels

In order to experimentally test whether stress affects exercise behaviour, stress has to be induced and its effects on exercise behaviour must be assessed. A unique study from Roemmich et al. (2003) demonstrated experimentally that a short exposure to acute stress reduces the time children engage in acute exercise. However, this chapter explores the effects on regular exercise; and while artificial stress induction methods are often being used to induce acute stress, a study in which participants are exposed to stressors for a longer period of time to investigate the effects of perceived stress on regular exercise levels has not yet been conducted. Therefore, quasi-experimental naturalistic investigations without a randomised group allocation examining effects of real life stress must be used to approximate causal explanations. One such study was conducted by Oaten and Cheng (2005) who used an academic examination period as real life stressor. The stressor significantly increased perceived stress levels in 30 Australian undergraduate students when compared to 27 fellow students who did not undergo an exam period. Analyses revealed that the stress group showed significant reductions in exercise frequency, duration, and reported ease of exercise during the exam session compared to the baseline measurement, while the control group did not change their exercise behaviour. This finding corroborates former results of a very similar naturalistic study from Steptoe et al. (1996) who also found detrimental effects of exam stress on exercise duration in 115 students, while no change occurred in a control group of 65 fellow students. Other prospective studies which compared participants’ exercise behaviour in time periods with and without exposure to stressors point into a similar direction (see Stults-Kolehmainen and Sinha 2014, pp. 104–105).

2.3.2 Exercise Reduces Stress Levels

This section aims at summarising experimental evidence on the effects of regular exercise on perceived stress levels in non-clinical populations. Therefore, only
studies which fulfill the following criteria will be included in the following literature overview: (1) The study is a randomised controlled trial (RCT) with at least one non-exercise control group and at least ten participants in each group; (2) the study examined a non-clinical population without any diagnosed disorders or illnesses; (3) the exercise intervention was longer than just one session; (4) the exercise intervention group(s) did not get any additional non-exercise related treatments like for instance health education or meditation (i.e., studies in which Yoga, Taiji, or Quigong exercises contained extra breathing or meditation parts were also excluded). Eleven studies which fulfilled all criteria were identified. Their main findings are depicted in Table 1 and will be summarised below.

Significance of Effects Five of the eleven RCT studies did not find the exercise intervention to have any effect on perceived stress levels [3, 4, 6, 9, 13]. All studies in which the exercise intervention did have a significant effect on perceived stress levels found exercise to reduce perceived stress [1, 2, 5, 7, 8, 10]. However, in two of these studies [1, 2], the post-intervention stress levels in the intervention group and the control group did not significantly differ from each other. While it is possible to argue that the nutrition education control group in study [1] also had a stress reduction effect, this explanation falls short with regard to the no-treatment control group in study [2]. This means four studies provided experimental support for the assumption that exercise can reduce perceived stress levels; yet, only one of these studies [8] found a significant interaction effect, indicating not only lower post-intervention stress values in an exercise group but also a significant stress reduction over time. Overall, at most half of the presented RCT support the assumption that an exercise intervention reduces perceived stress levels; however, no contrary effects were found, i.e. exercise interventions did not seem to cause increases in perceived stress levels.

Worksite Interventions and Job Related Stress Six studies approached participants in their leisure time [1, 2, 5, 6, 7, 13], five studies recruited participants at a certain worksite [3, 4, 8, 9, 10]. In three of the five worksite studies, participants also exercised at work [3, 4, 9]; interestingly, none of these three studies found significant effects on perceived stress levels. However, it is important to note that the three studies are also the only trials which assessed perceived job related stress by means of job stress questions – all other studies measured perceived stress by means of the Perceived Stress Scale (Cohen et al. 1983). A missing effect in worksite exercise studies [3, 4, 9] could thus indicate that exercising at work is not as effective in reducing stress or that general perceived stress levels but not specific job related perceived stress levels are reduced by engaging in exercise. Future studies need to further investigate this possible difference between study settings.

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3One of the studies is the study from O’Dougherty et al. (2012); as it also tested the stress buffer effect it is listed in Table 2 [#13]. The authors did not find a significant intervention effect on perceived stress levels.
Table 1  Overview of RCT examining the effects of exercise on perceived stress

<table>
<thead>
<tr>
<th>[Number]</th>
<th>Authors, year; country</th>
<th>Sample</th>
<th>Groups and intervention design</th>
<th>Effects of exercise intervention on PS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>Setting; profession, (if given) exercise background subjects</td>
<td>Age: M (SD)</td>
</tr>
<tr>
<td>[1]</td>
<td>Castro et al., 2002/King et al. 2002; USA</td>
<td>100 (85)</td>
<td>Leisure time; sedentary women caring for relatives with dementia</td>
<td>62.7 (9.16)</td>
</tr>
<tr>
<td>[2]</td>
<td>Connell &amp; Janevic 2009; USA</td>
<td>157 (137)</td>
<td>Leisure time; women caring for a spouse with dementia</td>
<td>66.8 (9.4)</td>
</tr>
<tr>
<td>[3]</td>
<td>Eriksen et al. 2002; Norway</td>
<td>860 (628)</td>
<td>Worksite; Norwegian postal services employees</td>
<td>37.4 (n/a)</td>
</tr>
<tr>
<td>[4]</td>
<td>Grouningsæter et al. 1992; Norway</td>
<td>79 (76)</td>
<td>Worksite; physically inactive insurance employees</td>
<td>n/a</td>
</tr>
<tr>
<td>Reference</td>
<td>Age</td>
<td>Setting</td>
<td>Intervention</td>
<td>Outcome</td>
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| Hopkins et al. 2012; USA | 75 (45) | Leisure time; healthy, sedentary young adults (18–36 years) | IG1: Aerobic exercise gym training (30 min, 4x/week, treadmill walk/jog ≥ 3.5 mph)  
IG2: Same as IG1 but additionally exercise training on the post-intervention test day  
CG1: No training and no exercise on test day  
CG2: No training and exercise on test day | 4 weeks | PSS | ANOVA: interaction (time x group): sig (PS reduced only in IG2; PS reduction larger in IG2 than in CG1/2) |
| Imayama et al. 2011; USA | 439 (438) | Leisure time; overweight/obese postmenopausal women | IG1: Moderate-to-vigorous intensity aerobic exercise (45 min, 5x/week [3 supervised], 70–85 % max HR)  
IG2: Dietary weight loss programme  
IG3: Combined diet and exercise programme  
CG: No treatment | 12 months | PSS | ANCOVA pre-post IG1 compared to CG: ns |
| King et al. 1993; USA | 357 (n/a) | Leisure time; adults aged 50–65 years; less than 2x/week regular exercise | IG1: Lower intensity, home-based exercise (30 min, 5x/week, 60–73 % max HR)  
IG2: Higher intensity, home-based exercise training (1 h, 3x/week, 73–88 % max HR)  
IG3: Higher intensity, group-based exercise training (same as group 2)  
CG: No treatment | 12 months | PSS-14 | ANCOVA post all IGs-CG: sig (PS lower in all IGs)  
ANCOVA post IG1-IG2-IG3-CG: sig (PS lower in IG1 & IG2 than in CG) |
| Norvell and Belles 1993; USA | 48 (43) | Worksite and leisure time; male state law enforcement officers, no regular exercise | IG: Circuit weight training programme (20 min, 3x/week, 8–12 repetitions)  
CG: No treatment | 16 weeks | PSS-14 | MANOVA interaction (time x group): sig (PS reduction in IG but not in CG) |

(Fortsetzung)
<table>
<thead>
<tr>
<th>Authors, year; country</th>
<th>Sample</th>
<th>Groups and intervention design</th>
<th>Effects of exercise intervention on PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>[9] Sjögren et al. 2006; Finland; Cluster RCT</td>
<td>90 (90) Worksites; office workers</td>
<td>45.7 (8.5) IG: Progressive light resistance training during working day (6 min, 5–8x/week), 3x20min physiotherapist group guidance CG No treatment</td>
<td>15 weeks; cross-over design</td>
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<tr>
<td>[10] Taylor, 1991; USA</td>
<td>111 (102) Worksites; female nurses (working at least 3 days/week)</td>
<td>39.1 (n/a) IG1: Aerobic exercise activities (20 min, 3x/week, 75 % max HR [220-age]) IG2: Music (20 min, 3x/week; subjects selected stress reducing music) CG No treatment</td>
<td>6 weeks</td>
</tr>
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</table>

Notes: N number of participants, N* number of participants included in analyses, M mean, SD standard deviation, IG intervention group, CG control group, max HR maximal heart rate, PS perceived stress, PSS perceived stress scale (PSS-14 = 14 item version), CJSQ Cooper job stress questionnaire, VRS visual rating scale, ANCOVA analysis of covariances, sig significant, ns not significant, n/a no information
Exercise Setting  As stated before, three studies asked participants to exercise at work and did not find any effects on perceived stress levels [3, 4, 9]. In the remaining studies participants engaged in an exercise programme individually at home [1, 2, 7] or at exercise facilities [5, 6, 7, 8, 13]. All studies which used an individual home-based exercise intervention training found reductions in perceived stress; the comparison between a home- and a group-based intervention in study [7] suggests furthermore that home-based exercise might be more effective in reducing perceived stress. This could be explained by the fact that home-based exercise can be done individually at any time; apart from that it costs less time as there is no need to travel to special exercise facilities – which might be especially beneficial for persons with little time. However, participants in studies [5] and [8] had to travel to an exercise facility 3–4 times per week in order to engage in their training programmes and they nonetheless experienced a clear stress reduction; yet, they also exercised on their own.

Exercise Type, Frequency, Duration and Intensity  Only two studies used a weight training exercise intervention [8, 9]; one weight training study did not find any effects on perceived stress [9] while the other one did find a significant interaction effect [8]. All other studies focussed on aerobic exercise and similarly half of them found that the exercise intervention was able to reduce participants' stress levels. Unfortunately, no study directly compared the effects of aerobic and anaerobic exercise on perceived stress levels. The exercise intervention programmes varied widely with regard to intensity and frequency, with 2–8 sessions per week ranging from 6–60 min per session lasting for 4 weeks to 6 months. Reductions in perceived stress have been found in exercise groups with low to moderate and in groups with higher training intensities. Study [7], for instance, found a moderate (30 min, 5x/week, 60–73 % maximum heart rate) and a higher intensity aerobic programme (60 min, 3x/week, 73–88 % maximum heart rate) to have comparable stress reduction effects. This indicates that moderate as well as higher intensities can lead to stress reductions; however, low to moderate intensity exercises should not be too short [9] and should be performed most days of the week [7], which is also in line with general physical activity guidelines (e.g., WHO 2010). Future studies should look more closely into the dose-response relationship to allow for more specific exercise recommendations.

Acute Effects of Regular Exercise  Another interesting finding emerged in the study from Hopkins et al. (2012) [5]. A significant stress reduction was only evident for participants who had also exercised on the post-intervention testing day; participants who underwent the same programme but did not exercise on the testing day did too show stress reductions but the changes were not significant (however, this effect might partly base on dissimilar baseline values). This finding indicates that acute exercise effects – which are not part of this overview – might also play a role with regard to perceived stress levels. It is indeed plausible that positive short-term effects on mood and acute stress levels influence how participants rate their stress levels even if they are being asked to rate their stress levels with regard to the last weeks/
months. Therefore, it might be beneficial for future studies to assess whether participants have engaged in exercise on the day of the assessment.

### 2.3.3 Conclusion

Overall, experimental evidence examining the relationship between physical exercise and perceived stress in non-clinical samples is promising but still limited. First, with regard to effects of stress on exercise, it is comprehensible that studies do not experimentally investigate how perceived stress affects chronic exercise. However, Roemmich et al. (2003) showed that effects of acute stress on acute exercise behaviour can be tested experimentally and other studies demonstrated that naturalistic controlled studies can provide valuable insights into the effects of perceived stress on exercise engagement (e.g., Oaten and Cheng 2005); yet, evidence is limited to children, students and academic stressors. In order to make more general predictions, studies with more heterogeneous samples and stressors are warranted. With the existing limitations in mind it can be concluded that higher perceived stress levels can lead to a reduction in exercise behaviour. This reasoning also corresponds with previously presented correlational evidence and findings from an extensive review on the effects of stress (including perceived stress as well as stressors) on exercise in which the authors conclude: “Overall, the majority of the literature finds the experience of stress impairs efforts to be physically active” (Stults-Kolehmainen and Sinha 2014, p. 81).

Second, with regard to effects of exercise on stress, experimental evidence suggests that participation in exercise can lead to reductions in perceived stress levels in healthy populations. Furthermore, no RCT has found a stress inducing effect of exercise. It seems legitimate to state that physical exercise can reduce general perceived stress levels. However, there is minimal evidence for the assumption that physical exercise can equally reduce perceived job stress and notwithstanding the experimental support found, ambiguities remain as significant stress reducing effects have only been identified in half of the investigated studies. Furthermore, most evidence depicted stems from the USA or Scandinavian countries and effects were often rather weak. More experimental studies investigating less specific samples need to further explore the effects of exercise on perceived stress to make findings more applicable.

All in all, taking into account existing correlational and experimental evidence, it can be concluded that exercise and perceived stress are most often negatively correlated with each other and that this negative relationship is caused by two effects: exercise reducing stress levels on one hand and perceived stress reducing exercise behaviour on the other hand. However, it should be kept in mind that many other factors also shape the relationship between exercise and stress (see Fuchs and Klaperski 2017). Apart from the direct links between exercise and stress discussed in this section, stress and physical exercise are also known to be indirectly related to each other. One such indirect connection is the so-called stress buffer effect which will be described in the following section.
Effects of Exercise on the Stress-Health Relationship

Section 2 showed that exercise can be beneficial for health because it reduces perceived stress levels. But physical exercise has even more stress regulative effects, as described in detail in Fuchs and Klaperski (2017). Two possible stress regulating mechanisms are the strengthening of psychosocial resources and the reduction of stress responses. Both mechanisms affect how stressors are being evaluated (cognitive appraisal) and how much a person reacts to stress (stress reactivity). This means that exercise can also lead to a reduction of negative stress effects, i.e., exercise can buffer existing or prevent from possible negative effects of stress on health. This relationship, in which exercise acts as moderator of the stress-health relationship, will be examined in the current section (see Fig. 1).

The hypothesis that exercise can buffer the negative effects of stress on health has existed since the 1980s and is called the stress buffer hypothesis of physical exercise (Gerber and Pühse 2009). It states that physical exercise moderates the stress-health relationship and reduces detrimental effects of chronic stress on health (Gerber et al. 2010). This suggests that in particular people, who are exposed to many stressors (or to a few severe stressors) and who perceive high levels of stress, benefit from physical exercise. Figure 2 illustrates how the stress buffer hypothesis pictures the relationship between stress, health and exercise behaviour: The health status of persons who are exposed to very few stressors/who experience low stress would not differ much as a function of physical exercise levels; however, for persons who are exposed to many stressors/who experience high stress levels engagement in physical exercise would make a big difference. Stress would cause negative effects on health in both high-stress groups, but due to the proposed stress buffer effect persons who engaged in physical exercise would have less health complaints than their inactive counterparts.

![Fig. 2 Exemplary illustration of the stress buffer effect of physical exercise](image-url)
Even though the stress buffer effect has been examined in at least 40 older and more recent empirical studies, the current state of research still provides some conflicting findings. In a narrative review on the stress-buffering effect of exercise, Gerber and Pühse (2009) concluded that the majority of studies supported the stress buffer hypothesis fully or partially but that many studies also did not find any evidence for the effect. Overall, the interaction effects between stress and exercise on health seemed rather small. Nevertheless, significant stress-buffering effects were found for mental as well as for physical health indicators. The following sections will provide a brief overview of the cross-sectional (Sect. 3.1), longitudinal (Sect. 3.2) and experimental evidence (Sect. 3.3) on the stress buffer effect of physical exercise (see also Gerber and Pühse 2009; Klaperski et al. 2012). It is important to note that unlike in the previous section, studies investigating perceived stress as well as studies investigating stressors (typically critical life events) will be included.

3.1 Stress Buffer Effect of Physical Exercise: Cross-Sectional Evidence

The empirical evidence for the existence of the stress buffer effect contains mainly cross-sectional studies. A clear majority of studies, about three-quarter, supports the stress buffer effect fully (e.g., Brown and Lawton 1986; Craike et al. 2010; Ensel and Lin 2004; Gerber et al. 2013b; Haugland et al. 2003; Heaney et al. 2014; Kaluza et al. 2002; Kobasa et al. 1982; Lochbaum et al. 2004; Yin et al. 2005) or partially (Brown 1991; Carmack et al. 1999; Gerber et al. 2010; Gerber et al. 2014; Klaperski et al. 2012; Norris et al. 1992; Sliter et al. 2014; Uebelacker et al. 2013; Zuzanek et al. 1998). Effects have been found for physical exercise as well as physical fitness, for perceived stress as well as single stressors or stressful life events and for school and university students, managers, mothers, employees and young, middle-aged and older adults.

Full support for the stress buffer hypothesis was for instance found in a study from Lochbaum et al. (2004) in which 275 undergraduate students completed the Perceived Stress Scale and a health symptom checklist. A hierarchical regression analysis revealed a significant interaction between perceived stress and strenuous exercise, with students who frequently engaged in strenuous exercise reporting less health complaints when they were stressed than less active, stressed students. Examining a very different sample of 4720 young mothers, Craike et al. (2010) also found that the effects of perceived stress on mental health were buffered by physical exercise. Results of a study investigating the effects of stressful life events in a sample of more than 1200 Americans also supported the stress buffer effect of physical exercise with regard to psychological as well as physiological health (Ensel and Lin 2004). This outcome corresponds with many other similar studies which looked at the moderation of stressor effects (e.g., Brown 1991; Brown and Siegel 1988; Carmack et al. 1999; Sigfusdottir et al. 2011; Yin et al. 2005). Noteworthy, Brown (1991) found this effect not only with regard to physical exercise levels but also for objectively assessed cardiorespiratory fitness levels; a finding which is also
supported by more recent studies in which cardiorespiratory fitness moderated the effects of perceived stress on mental health and cardiovascular risk factors (Gerber et al. 2013b, 2016). Furthermore, Gerber et al. (2010, 2013a) found a stress buffer effect not only with regard to objectively measured fitness but also with regard to perceived fitness.

Other studies have found the stress buffer effect less consistently. Zuzanek et al. (1998) for instance showed that exercise buffered stress in men but not in women. Other studies did not find stress-buffering effects for all health variables they examined (e.g., Brown 1991; Carmack et al. 1999; Gerber et al. 2014). Stults-Kolehmainen et al. (2014) did find a significant interaction only for one of three stressor types they assessed (namely for major life events), but more importantly the interaction was not in line with the assumptions of the stress buffer hypothesis as it was found for low levels of stress: only at low levels of stress, higher exercise levels were related to fewer health problems. Another inconsistency emerged in a longitudinal observation from Klaperski et al. (2012). The authors conducted cross-sectional analyses at both longitudinal measurement points which were 10 months apart and found a significant cross-sectional stress-buffer effect of physical exercise at only the latter of the two measurement points. This reflects a general problem of cross-sectional studies as studies often assess variables over a very short period of time. People often change their physical activity levels or undergo more and less stressful time periods – cross-sectional studies might assess subjects in a status of change whereby effects will be harder to detect.

However, this explanation can of course not fully clarify why several other studies did not find a stress buffer effect of physical exercise (e.g., Gerber and Pühse 2008; Gogoll 2004; Moksnes et al. 2010; Roth et al. 1989; Siu et al. 2000; Skirka 2000) or fitness (e.g., Gerber et al. 2013a; Roth et al. 1989). Siu and colleagues (2000), for instance, found no support for the assumption that exercise frequency moderates the relationship between occupational stress and physical or mental health in a sample of 280 Chinese employees. Results from Skirka (2000) did not show that participation in university sports teams moderated the effects daily hassles had on students’ mental health – findings which resembled the outcome from a study in which the authors did not find a stress buffer effect for elite youth athletes (Gerber et al. 2011). These latter findings imply that it might be more important to examine the level of actual fitness or participation in exercise than to examine certain exercise groups, as members of comparison groups can still be physically active.

Overall, compared to the many studies which found support for the stress buffer effect of physical exercise/fitness, only a minority of studies did not find a stress buffer effect. Hence, it can be assumed, that physical exercise as well as fitness might be able to buffer detrimental effects of stressor exposure and high levels of perceived stress on health. Noteworthy, this might not only hold true with regard to one’s own health: Burton et al. (2012) found that supervisors who experienced high levels of workplace stress showed less abusive supervision behaviour towards their subordinates when they regularly engaged in exercise. However, this evidence is cross-sectional and does not allow for causal conclusions. It is key to further examine existing longitudinal and experimental evidence.
3.2 Stress Buffer Effect of Physical Exercise: Longitudinal Evidence

About a dozen studies have examined the stress buffer effect longitudinally. The time period differs greatly between studies, with studies following a sample of participants over a time period of 9 weeks (Roth and Holmes 1985) to 6, 10 or 30 years (Harris et al. 2006; Holtermann et al. 2010; Unger et al. 1997). Slightly more than half of the longitudinal studies supported the stress buffer hypothesis fully (Brown and Siegel 1988; Harris et al. 2006; Howard et al. 1984; Klaperski et al. 2012) or partially (Fuchs and Appel 1994; Holtermann et al. 2010; Roth and Holmes 1985; Unger et al. 1997); the other half of the studies did not find a significant stress buffer effect in their data (Fuchs and Hahn 1992; Fuchs and Leppin 1992; Fuchs et al. 1994; Gerber 2008; Manning and Fusilier 1999; Röthlisberger et al. 1997; Uebelacker et al. 2013).

In one of the earliest studies, Howard and colleagues (1984) showed for a sample of 278 managers that physical activity moderated the effects of stressful life events on somatic complaints over the analysed period of 4 years. Harris et al. (2006) even investigated 424 depressed adults at four measurement points over a time period of 10 years. By using multilevel modelling, the authors found physical activity to significantly buffer the effects of negative life events on depression. A shorter time interval of 10 months was used by Klaperski et al. (2012) who explicitly examined the effects of chronic exercise and stress patterns by only including subjects who reported the same exercise and stress levels at both measurement points. In line with the assumptions of the stress buffer hypothesis, analyses revealed significantly less mental health complaints in physically active employees who reported higher levels of occupational stress compared to their inactive, stressed colleagues. Another 9-week long study supported the stress buffer hypothesis furthermore for objectively assessed levels of physical fitness, however, effects were not significant with regard to all dependent health variables the authors examined (Roth and Holmes 1985).

A rather different approach with regard to investigated time frame and chronicity of examined exercise and stress levels was adopted by Holtermann et al. (2010) and Uebelacker et al. (2013). As part of the so-called Copenhagen Male Study, Holtermann and colleagues carried out a 30-year follow-up analysis by relating information more than 4943 employees provided in 1970/71 to ischaemic heart disease mortality during the following 30 years. It was shown that men with low and medium physical fitness levels had a significantly twofold increased risk of dying from an ischaemic heart disease when they experienced high physical work demands, while this was not the case for fit men. Similarly, Uebelacker et al. (2013) used exercise and stress data from a baseline measurement to predict depression in more than 91,900 post-menopausal women 3 years later, but did not find a significant stress buffer effect. Even though these findings are interesting, it is questionable whether this kind of long-term predictive analysis is meaningful; it is very likely that subjects will have changed their exercise behaviour and that they will have experienced more and less stressful times. However, other longitudinal studies which did assess exercise and stress levels at different measurement points did not
find any significant interaction effects either (e.g., Fuchs and Leppin 1992; Gerber 2008; Röthlisberger et al. 1997).

Overall, it can be concluded that a majority of longitudinal studies on the stress buffer hypothesis found evidence for the hypothesis’ assumptions. Similarly to the cross-sectional findings, a stress buffer effect has been observed for physical exercise as well as for physical fitness and with regard to perceived stress as well as to stressors; however, compared to previously presented cross-sectional evidence, less studies examined the effects of fitness and perceived stress. Even though longitudinal findings can provide valuable insights into the stress buffer effect, experimental studies are needed to properly test the assumptions of the stress buffer hypothesis. Thus, the next section will summarise existing experimental evidence on this topic of research.

3.3 Stress Buffer Effect of Physical Exercise: Experimental Evidence

In their review, Gerber and Pühse (2009) criticised the lack of experimental findings on the stress buffer hypothesis. To the best of our knowledge, there are still only three studies which have examined the stress buffer effect experimentally (Klaperski and Fuchs 2014; Latimer et al. 2005; O’Dougherty et al. 2012). In addition, there has been one quasi-experimental study on the stress buffer effect (Norris et al. 1992). Key aspects of all four studies are listed in Table 2. After a short description of each study, a summary of the main findings will be provided below.

Norris et al. (1992) conducted a quasi-experimental field study with 60 adolescents. The participants completed either a high intensity aerobic training, a moderate intensity aerobic training, a flexibility training or no training. After 10 weeks of training a stress buffer effect was found for the members of the high intensity aerobic training group. The first experimental study testing the stress buffer hypothesis was conducted by Latimer et al. (2005). The authors examined a small sample of 23 adults with spinal cord injury (even though this is a specific clinical population the study was included due to the shortage of experimental evidence). They randomly assigned their participants to either a 6-month exercise programme or a control group. Correlational analyses showed that the significant negative correlation between perceived stress and mental health at time of the baseline lost its significance in the exercise group after 3 months as well as at the end of the intervention after 6 months. More experimental evidence for the stress buffer hypothesis was provided by O’Dougherty and colleagues (2012) who investigated stress and health in a larger sample of 303 young US women. Participants were healthy and insufficiently active and they were randomised into a 16 week long

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4Taylor (1991) (see Table 1 [10]) did also test for stress-exercise interaction effects on depression and anxiety. However, they used pre-intervention stress levels for their calculations, thus the finding will not be listed here.
<table>
<thead>
<tr>
<th>Number</th>
<th>Authors, year; country; design</th>
<th>Sample</th>
<th>Groups</th>
<th>Analysis of stress buffer effect</th>
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| [11]   | Norris et al., 1992; UK; CT    | 80     | Sample; number of participants in study groups | **Sample:** School students, 48% female; IG1: n = 22/14 at t1/t2; IG2: n = 19/15 at t1/t2; IG3: n = 19/15 at t1/t2; CG: n = 20/16 at t1/t2  
**Age:** 16.7 (n/a)  
**Study groups:** IG1: High intensity AT (20–30 min, 2x/week, 70–75 % max HR)  
IG2: Lower intensity AT (20–30 min, 2x/week, 50–60 % max HR)  
IG3: Flexibility training (20–30 min, 2x/week)  
CG: No treatment  
**Duration of intervention:** 10 weeks  
**Points:** t1 & t2: pre- & post-  
**Measures:** Stress: PSS, LEQ*  
**Health:** SIRS*, MAACL-D/A  
**Fitness:** Step fitness test (LUST)*  
**Tests used to examine the SBE and results:** Correlation analysis PSS & depression/anxiety: sig SBE for IG1 (compared to average value of all other groups)  
**NB:** Further comments: Fitness increased significantly in IG1 only; no actual SBE group comparisons reported; *sig reduction PS levels in IG1 (see Sect. 2.3)* |
| [12]   | Latimer et al., 2005; Canada; RCT | 34     | Sample | Sample: Adults with spinal cord injury; IG: n = 21/13 at t1/t3, 31% female; CG: n = 13/10 at t1/t3, 25% female  
**Age:** 40.0 (11.1)  
**IG:** Exercise programme (1 h, 2x/week; aerobic & anaerobic elements, small groups)  
CG: No treatment  
**Duration of intervention:** 6 months  
**Points:** t1, t2 & t3: pre, mid- & post-  
**Measures:** Stress: PSS  
**Health:** CES-D, PQOL  
**Tests used to examine the SBE and results:** Correlation analysis PSS & PQOL/depression: sig SBE for IG (correlations between stress & health at t3 in IG1 not significant anymore)  
**NB:** Further comments: No fitness assessment |
| [13]   | O’Dougherty et al., 2012; USA; RCT | 372    | Sample | Sample: Insufficiently active, healthy women from WISER trial; IG: n = 203/162 at t1/t2; CG: n = 169/141 at t1/t2  
**Age:** 25.2 (3.5)  
**IG:** Aerobic exercise programme (30 min, 5x/week; progressing from 65 % to 85 % max HR)  
CG: No treatment  
**Duration of intervention:** 16 weeks  
**Points:** t1 & t2: pre- & post-  
**Measures:** Stress: Adjusted LES, PSS*  
**Health:** CES-D,  
**Tests used to examine the SBE and results:** Multivariate linear regression Adjusted LES & CES-D: sig SBE for IG (at t2 life events increased depression in CG only)  
**NB:** Further comments: No fitness assessment; no effect on PS levels (see Sect. 2.3) |
| Klaperski & Fuchs, 2014; Germany; RCT | Insufficiently active, healthy male employees; IG1: n = 51/38 at t1/t2; IG2: n = 51/35 at t1/t2; CG: n = 47/31 at t1/t2 | 45.8 (10.5) | IG1: Aerobic running training (1 h, 2x/week, 60–80 % max HR) IG2: Relaxation training (1 h, 2x/week) CG: No treatment | 12 weeks t1 & t2: pre- & post-intervention | Stress: PSS, JSS, TICS Health: SF-12, GBB Fitness: graded fitness test | ANCOVA & regression TICS & SF-12/GBB: sig SBE for IG1 & IG2; regression JSS & SF-12: sig SBE for subjects with high fitness NB: Fitness increased significantly in IG1 only |

*Notes: N number of participants, M mean, SD standard deviation, AT aerobic training, IG intervention group, CG control group, SBE stress buffer effect, t1/t2/t3 first/second/third point of measurement, max HR maximal heart rate, ANCOVA analysis of covariances, sig significant, ns not significant, n/a no information, WISER women in steady exercise research trial. Measures: * measure was not used to examine the SBE, PSS perceived stress scale, PS perceived stress, LES life event survey, LEQ life events questionnaire, SIRS seriousness of illness rating scale, MAACL-D/A multiple affect adjective checklist-depression/anxiety, LUST Louisiana university step test, PQOL perceived quality of life scale, CES-D center for epidemiologic studies depression scale, Adjusted LES composite life events scale which contains items from different life event scales, JSS job stress survey, TICS Trier inventory for chronic stress, SF-12 short form health survey, GBB Gießener complaint questionnaire*
progressive aerobic exercise group or a control group. It was shown that participation in the exercise programme buffered the effects of negative life events on depressive symptoms. In the last experimental study, Klaperski and Fuchs (2014) focussed on the effects of perceived stress instead of negative life events. They randomly allocated 149 male inactive employees to an aerobic running group, a relaxation group, or a control group and examined the participants’ cardiorespiratory fitness and health levels before and after a 12-week intervention period. Analyses of the participants’ stress and health levels after the intervention revealed that the exercise as well as the relaxation programme had buffered negative effects of chronic stress on subjective health levels and health complaints. However, the stress buffer effect was not consistently found in all analyses and for all investigated stress and health variables. The main findings of all quasi-experimental and experimental studies will be summarised below.

**Significance of Effects** All experimental studies supported the assumption that participation in physical exercise buffered detrimental effects of stress on health; the effect was found for men, women and adolescents from different backgrounds. However, effects which emerged were rather small and should still be interpreted with caution, especially for studies [11] and [12]: Norris et al. (2012) compared the high intensity group with the average of all other groups, which means it was not possible to identify the effect of any other single training programme, ruling out any conclusions with regard to effects of different exercise trainings. Latimer et al. (2012) used a very small number of participants and a rather weak statistical approach; the authors themselves regarded their findings tentatively as first preliminary experimental support of the stress buffer role of exercise. Furthermore, findings from Klaperski and Fuchs (2014) demonstrated how much the significance of the effect depends on the type of analysis chosen. Their results also illustrated that an alternative relaxation programme led to comparable stress buffer effects, suggesting that a stress buffer effect can be achieved not only by means of physical exercise.

**Stress Measures** Three studies examined the buffer effect with regard to perceived stress [11, 12, 14], only study [13] examined it with regard to stressful life events. As all studies supported the stress buffer effect it can be concluded that exercise acts as buffer for negative effects of stressors as well as perceived stress – a finding which is also supported by correlational evidence. As perceived stress can be seen as result of a transactional process which could have already been influenced by physical exercise in other ways (see section 2), the stress buffer effect might be stronger with regard to stressors than with regard to perceived stress. However, there is no experimental evidence to test this assumption; future studies should include and test the stress buffer hypothesis with regard to stressors and perceived stress levels.

**Health Measures** Stress buffer effects were found for mental [11, 12, 13] as well as for physical health [14]. However, looking closer at the evidence, studies investigating mental health strongly focussed on depressive symptoms; anxiety [11] and quality of life [13] were each only investigated once as alternative mental health
indicators. In line with the presented correlational evidence, exercise seems to buffer effects on mental as well as on physical health. Yet again, further experimental research needs to test this conclusion in a more systematic way, especially because “health” is such a broad construct. Instead of every study investigating other health measures, it would be beneficial to agree on a few valid and suitable health indicators for each health aspect and to systematically examine these indicators in different studies with different samples.

Exercise Type and Fitness  All exercise interventions focussed on aerobic exercise; thus, it cannot be concluded whether other types of exercise, e.g. weight training, would have had similar effects. However, study [12] did also include weight training elements and did find a stress buffer effect. As aerobic exercise programmes aim at increasing aerobic fitness levels, finding a stress buffer effect of fitness could reflect the importance of aerobic exercise training. Yet, only one study [14] also examined the role of cardiorespiratory fitness and results implied that participation in the exercise intervention had stronger buffer effects on health than increases in fitness levels. Unfortunately, correlational studies did hardly examine this question either, but in line with findings from Brown and Siegel (1988) it stands to reason that other non-aerobic exercise types can buffer stress like aerobic exercise types; the buffer effect does seemingly not primarily occur as a function of aerobic fitness. However, supporting experimental evidence is sparse and it would be very desirable if studies soon addressed this question by comparing stress buffer effects of different exercise types and by further examining the role of aerobic fitness.

Exercise Frequency, Duration and Intensity  Aerobic exercise interventions lasted from 10 weeks [11] to 6 months [13]. Exercise intensities were quite similar (moderate to intense) and participants in studies [12, 13, 14] trained for a comparable time of 2–2.5 h per week. Participants of the high-intensity training group in study [11] exercised only half that much, however, the training intensity was higher. As previously stated, even though study [11] included interventions with different exercise intensities, the authors did not analyse the differences between the three exercise groups. Therefore, it cannot be stated whether less intense aerobic exercise programmes are less effective than more intense trainings. Overall, the studies suggest that engagement in 2 h of moderate to intense aerobic exercise per week is sufficient to buffer negative effects of stress. However, it must be kept in mind that all three experimental studies [12, 13, 14] examined participants who were sedentary or hardly engaging in physical exercise. Thus, future studies should not only examine the effects of different exercise intensities but should also explore what effects increased exercise levels have in more active samples.

In summary, it can be stated that there is clear cross-sectional, longitudinal and experimental evidence for the stress buffer effect of physical exercise (and/or fitness), but many more questions need to be addressed. The conclusion which Gerber and Pühse drew in 2009 at the end of their review still holds true in light of the newly published evidence: “Given that the direction of the interaction effects was generally consistent, showing that exercise alleviates stress, we feel confident to
advertise exercise as a stress-management strategy. Although exercise may not always help, high exercise levels in periods of increased stress do not generate additional stress” (2009, p. 815). However, none of the described studies provided insights into the possible mechanisms of the stress buffer effect of exercise. As stated at the very beginning of this section, it is widely assumed that the so-called cross stressor adaptation effect (see Gerber 2017) as well as changes in psychological resources mediate the stress buffer effect of exercise (Gerber and Pühse 2009). Numerous studies have investigated the mechanisms possibly underlying the stress buffer effect without simultaneously examining the stress buffer effect. Only one study examined physiological and psychological mechanisms in combination with the stress buffer effect, indicating that the stress buffer effect of physical exercise cannot easily be explained by means of physiological and psychological mechanisms (Klaperski and Fuchs 2017). However, more empirical evidence is needed in order to draw sound conclusions.

4 Conclusion

Experiencing high levels of stress over an extended period of time is one of the biggest risks for mental and physical health (Chrousos 2009). Cross-sectional, longitudinal and experimental studies provide support for the stress reducing effects of physical exercise on the one hand and the stress buffer effect of physical exercise (and/or fitness) on the other hand. However, many relevant questions with regard to practical implications remain unanswered for both topics: What type of exercise does lead to a stress buffer effect and/or to a direct stress reduction? How much and how vigorous should individuals train to maximise the potential of exercise to regulate stress? If exercise buffers stress effects, what health aspects benefit the most? Future studies investigating these questions would aid in developing clear exercise recommendations to prevent negative stress effects and to effectively protect one’s health in stressful times. A better understanding of the underlying mechanisms of the stress buffer effect of physical exercise would further enhance the applicability of findings.

Even though underlying mechanisms of the stress regulative effects discussed in this chapter have not yet been fully understood, it is useful to recommend exercise as a strategy to prevent and regulate stress. Drawing on the findings reported in this chapter, exercise seems to be effective in reducing and regulating stress, particularly in very stressful periods. Evidence supporting that stress can have negative effects on exercise levels further indicates that physical exercise might fulfil its stress regulating role best when it is being done regularly. Ideally, exercising should become a habit (Fuchs 2007) but at the same time it should never be perceived as an additional stressor (Stults-Kolehmainen and Sinha 2014). Other activities, for instance relaxation programmes, might have similar stress regulative effects, but going beyond stress regulation, exercise is undisputable the activity which benefits mental, physical and psychosocial health in many other ways the most (e.g., O’Donovan et al. 2010; Raglin and Wilson 2012).
References


