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# Change and Persistence of Gender Disparities in Academic Careers of Mathematicians and Physicists in Germany

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**ABSTRACT**

This article discusses whether or not gender-related disparities exist within the academic fields of mathematics and physics regarding the application of career knowledge and the experiences of disadvantage in relation to recognition of performance, assessment of professional competencies, and integration into networks. To answer this question, primary data was collected with a structured online survey addressing graduates in both academic fields (n=5,174). The article considers a subsample of respondents working at a university or university of applied sciences (n=1,613). Apart from the gender perspective, other factors potentially influencing the academic careers of mathematicians and physicists, such as being in a certain subject, age cohort or having children, are also considered. Some of the key findings are: a) more gender differences occur in mathematics than in physics; b) the experiences of disadvantage in the workplace constitute a cross-disciplinary phenomenon caused by the gender differentiating academic culture; and c) more female than male academics in both disciplines accept constraints or abandon career goals due to child care.

**KEYWORDS**

academic career; gender disparities; mathematics; physics; German higher education system; career knowledge

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## INTRODUCTION

An increase in women at all qualification and status levels at universities has been evident in Germany over the last 25 years. This development has resulted in a slow, but steady reduction in the asymmetrical gender ratio – at least regarding the vertical segregation in the German higher education system (GWK, 2014). Yet, the so-called leaky pipeline, i.e. the decrease of the percentage of women from one qualification or status level to the next, is generally still an appropriate metaphor, even though the newest figures hint at a gradual dilution of this phenomenon (GWK, 2014). While ten years ago, obtaining a doctoral degree was regarded as the critical obstacle for women aiming at an academic career, now it is the postdoctoral phase instead that constitutes the decisive hurdle (Konsortium Bundesbericht Wissenschaftlicher Nachwuchs, 2013).

The German academic career is generally not tenure track: by law a junior staff member cannot be promoted to a professorial position within the same institution. Regulations concerning employment in the higher education system in Germany, the Wissenschaftszeitvertragsgesetz (WissZeitVG), stipulate that academic personnel can be employed with a fixed-term contract for up to six years. After completing a doctorate, further fixed-term employment is possible for up to six years. Should the transition to a contract of unlimited duration (e.g. professorship) not succeed within these twelve years, further employment at a university is only possible through externally funded projects. The regulations permit parents to extend the duration of fixed-term employment by up to two years per child in need of care.

The prerequisites for appointment to a professorship at a German university are a completed programme of higher education, pedagogical suitability and usually an outstanding doctorate. Additional academic achievements are necessary, such as habilitation, which generally includes writing a habilitation treatise (often while working in a postdoctoral position as non-professorial staff at a university with little leeway in decision-making) and an examination process. Since 2001 a fixed-term junior professorship (sometimes with, but often without tenure track) has become an established alternative to habilitation, especially in mathematics and the natural sciences. The junior professorship – not directly comparable to an associate professorship in the US or a lecturer or senior lecturer position in the UK – allows independent academic research and budget responsibility, as junior professors belong to the status group of professors. Experienced postdocs can also choose a third path and become a junior researcher group leader at universities or large non-university research institutions to qualify for a professorship or another academic leadership position.

To describe gender disparities in the academic careers of mathematicians and physicists, as well as persistence or change over time, it must be clarified first, whether and to what extent the metaphor of a leaky pipeline is applicable to both disciplines under investigation.

*Table 1: Proportion of women at different qualification and status levels in higher education in Germany in mathematics and physics (selected years)*

| | 1980 | 1990 | 2000 | 2015[a] |
|---|---|---|---|---|
| Students | | | | |
| mathematics | 35.2 | 36.6 | 43.7 | 45.9 |
| physics | 9.1 | 10.1 | 17.1 | 27.0 |
| in total | 36.7 | 38.3 | 46.1 | 48.0 |
| Diploma or master's degrees[1] | | | | |
| mathematics | 14.9 | 28.6 | 24.6 | 34.6 |
| physics | 6.1 | 8.4 | 9.8 | 20.0 |
| Doctoral degrees | | | | |
| mathematics | 4.9 | 11.7 | 23.0 | 25.3 |
| physics | 3.4 | 6.0 | 9.9 | 19.0 |
| in total | 19.6 | 27.8 | 34.3 | 44.7 |
| Habilitations (junior professorships[b]) | | | | |
| mathematics | 1.8 | 0.0 | 19.8 (22.2) | 6.8 (23.3) |
| physics | 1.3 | 4.0 | 7.7 (0.0) | 21.7 (28.9) |
| in total | 4.4 | 10.0 | 18.4 (32.4) | 28.3 (39.9) |
| Professorships | | | | |
| mathematics | 0.3 | 1.8 | 5.0 | 17.4 |
| physics | 0.9 | 0.5 | 2.8 | 10.8 |
| in total | 5.3 | 5.5 | 10.6 | 22.7 |

Source: Calculations based on the absolute numbers of the official higher education statistics in Germany; a: When separated by gender, only the numbers for 2015 are available for all qualification levels and status levels; b: Data for junior professorship has not been separated by gender continuously since the implementation, so the presented figures are the shares from 2002 (instead of 2000) and 2013 (instead of 2015).

The increase in the proportion of women in mathematics and physics (table 1) indicates similarities as well as differences. Since the 1990s, the two subjects have differed in the exhaustion of female recruiting potential at the status transition from degree to graduation and from graduation to habilitation/junior professorship (Langfeldt & Mischau 2015). Therefore, the leaky pipeline is still applicable to mathematics where the share of female academics diminishes from one qualification level to the next. In physics however, the crucial obstacle for female scientists has moved to the postdoctoral phase, so the leaky pipeline does not seem adequate to describe the situation in this field of study. Both disciplines have in common that, despite a steady increase in the percentage of women since the 1980s, few female scientists have acquired a professorship. This might be a reference to the existence of a so called "glass ceiling", the invisible barrier that keeps women from rising beyond a certain level in a hierarchy.

To date, no representative cohort analyses explaining the underlying causes and mechanisms for the leaky pipeline for mathematics and physics have been undertaken. Moreover, comparative studies on processes of persistence and change in gender disparities in academic careers in both disciplines are missing. However, there are numerous sociological approaches explaining the under-representation of women in leadership positions in science. Depending on their alignment, these approaches focus on individual, organisational, cultural, or structural social causes for the (re-)production of gender disparities in academic career development (e.g. Findeisen, 2011; Graf & Schmitt, 2011; Kahlert, 2013).

While this article relates to the strands of research focusing mainly on individual factors (the sociological micro-level of analysis) influencing the career path, such as the application of career knowledge, we assume that gender stereotypes (at the sociological macro-level of analysis) are omnipresent (e.g. Haghanipour, 2013) and connected with other explanations. Additionally, we refer to the life course hypothesis arguing that the typical work biographies of women are less continuous than those of men, which supposedly has adverse effects on their careers, as the labour market in general, and the profile of a scientist in particular, are based on the ideal of uninterrupted work (e.g. Kreckel, 2005).

Principally we assume that our sample of mathematicians and physicists employed in academia is aware of written and unwritten rules for advancement and shows little or no gender differences with respect to career knowledge. It is rather a question of whether and to which extent gender disparities exist in both disciplines regarding the application of career knowledge. Gender specific divergences due to professional restraints caused by caring for children will also be examined in this context. These family related restraints partially counteract strategic career planning or lead to breaks in career history, but are not to be considered as missing career knowledge.
In summary, the distribution of experiences of disadvantage in the (former) professional life of male and female respondents will be presented. To be able to find indications a) for reasons for the different development in mathematics and physics regarding the leaky pipeline and b) for persistence and change of gender disparities in academic careers in both subjects, we take a subject- and age cohort-comparing perspective, in addition to a gender perspective. Moreover, we interpret our findings in the light of theoretical assumptions and the results of earlier studies.

## DATA AND SAMPLE DESCRIPTION

The empirical basis of this article is quantitative data collected through an online survey conducted between October 2012 and February 2013 as part of the project 'Gender disparities in the occupational career of mathematicians and physicists within and outside traditional employment models'.[2] A total of 5,174 individuals with a degree in mathematics or physics took part in the survey. Most had been made aware of this study by scientific societies and professional associations as well as by equal opportunity commissioners of universities, universities of applied sciences and non-university research institutes. Consequently, the findings can be considered as being approximately representative for mathematicians and physicists who are members of scientific societies or professional associations. For the analysis in this article a subsample of 1,613 respondents who were employed at a university or university of applied sciences in Germany, either at the time of the survey or before reaching retirement age (e.g. emeriti), was used.

89.4 percent of the respondents in that subsample held a degree in physics and 10.6 percent a degree in mathematics (Table 2). While the German micro census estimates that there are more physicists than mathematicians in the population, physicists were over-represented in our sample. This is due to special support from the "Deutsche Physikalische Gesellschaft (DPG)", which comprises nearly 62,000 members (status quo 2017) and is the largest national physics association worldwide. The "Deutsche Mathematiker-Vereinigung (DMV)" also encouraged their members to take part in the study, but the association only has about 5,000 members.

*Table 2: Description of the sample (n= 1,613) by selected characteristics, subject and gender*

| n=1,613 | mathematics | | physics | |
|---|---|---|---|---|
| | male (n = 71) | female (n = 100) | male (n = 1,042) | female (n = 400) |
| gender distribution | 41.5% | 58.5% | 72.3% | 27.7% |
| average age (mean; standard deviation) | 42.4 years (11,2) | 38.2 years (9,6) | 41.7 years (13,0) | 36.2 years (8,9) |
| having child(ren) | 56.6% | 42.7% | 45.2% | 36.1% |
| finished doctoral degree | 82.6% | 59.2% | 70.0% | 60.1% |
| currently doing doctorate | 14.5% | 29.6% | 23.5% | 29.0% |
| working full-time | 78.9% | 74.0% | 72.0% | 59.0% |
| working part-time | 12.7% | 22.0% | 19.8% | 32.3% |
| having a professorship* | 61.4% | 50.0% | 47.2% | 30.1% |

*Only participants with a doctoral degree were asked about a professorship.

As can be seen in table 2, there was a different gender distribution turned out differently between the two disciplines, hinting at a disproportionately high participation of female respondents in the survey. This was more pronounced in mathematics than in physics: the percentage of women in full-time employment at higher education institutions at the time of the study was about 22.3 percent in mathematics and about 16.5 percent in physics (Statistisches Bundesamt, 2014).

The men surveyed were five years older than the women on average, but this age difference did not explain the occurring gender differences regarding parenthood. Considering only the over 40-year old respondents, 83 percent of men but only 65 percent of women in mathematics had children; in physics, this applied to 74 percent of men and 59 percent of women.

The lower proportion of women with a doctoral degree compared to men is due to the difference in age between the genders of the sample. When adding graduate participants and participants pursuing their doctorate at the time of the study, the gender differences reduce considerably. Regarding the extent of working time, more men than women were employed full-time in both disciplines, while the ratio was reversed among part-time workers. The comparatively high share of young male part-time workers in mathematics and physics mainly resulted from doctoral positions rarely being full-time. The same reason for part-time employment was given by many of the young female scientists in our sample. But women also mentioned compatibility of family and career as a decisive reason for part-time work. The significant gender difference becomes especially obvious when looking at the 35 to 55-year old respondents in the core phase of occupation. Here 95 percent of the men but only about 76 percent of the women were employed full-time in both subjects.

Of participants with a doctoral degree, 61.4 percent of male and half of female mathematicians had (or formerly had) a professorship. Among physicists, this applied to only half of the men and not quite one third of the women, which can be explained to a certain extent by age differences – the subgroup of female physicists was the youngest of the whole sample.

## THE APPLICATION OF CAREER KNOWLEDGE

Often used arguments for the under-representation of women in leading positions refer to deficits in women's ambition and motivation to lead (Elprana et al., 2012; Henn, 2012), as well as to the application of career knowledge (Vogel & Hinz, 2004). Career knowledge is understood as knowledge about the most important promotion criteria, i.e. performance requirements and strategic decisions that really matter for professional advancement (Fay, Hüttges & Graf, 2013, p. 28).

Being goal-driven is one essential aspect of career knowledge, normally evident in science by rapid career progression through the necessary qualification phases and status passages (Jungbauer-Gans & Gross, 2013). Fast completion of the various career steps is also considered an objective indicator for performance on an individual level. Yet, there are structural parameters such as the so called 12-years-regulation of the Wissenschaftszeitvertragsgesetz or the competitive pressure in the higher education system, that contribute to time being of career relevant importance (Kahlert, 2013).

Another crucial aspect of the application of career knowledge is fulfilling subject-specific cultural expectations and "rules of the game". A successful start to an academic career corresponds, for example, with the "right" choice of topic and subject for the doctoral thesis, the strategic choice of a doctoral supervisor, early institutional involvement and a postdoctoral stay abroad which seems almost compulsory, especially in physics. Furthermore, high intrinsic motivation and strong interest in a scientific subject are considered as higher-level requirements for a career in science. Fulfilling these preconditions rarely leads to professional success by itself; it needs to be complemented by the application of career relevant strategies (Cornils et al., 2012). Among those strategies often researched and considered as very important are for example (academic) visibility and extended job involvement (Gould & Penley, 1984; Henn, 2012).

**Target-oriented time-wise – be fast!**

While some studies analysing the duration of the transition from diploma or master's degree to starting a doctorate found little or no gender differences (e.g. Hauss et al., 2012; Mischau et al., 2010), our sample of male mathematicians and physicists needed less time for this status passage than their female counterparts.[3] The fastest 25 percent of the male respondents started their doctorate only one month after finishing their studies; the second fastest 25 percent two months; and the third fastest 25 percent six months after graduation. The fastest 25 percent of the female participants of our survey also began their doctorate one month after finishing their studies. The second quarter, in contrast, started three months and the third quarter eight months after getting a degree.

*Table 3: Indicators for time-wise target-orientation regarding doctoral and postdoctoral phase by subject and gender*

| | mathematics | | physics | |
|---|---|---|---|---|
| | male | female | male | female |
| average time to doctorate in months (mean, standard deviation) | 39.6[ab] (14.08) | 47.8[a] (20.21) | 47.0[b] (15.48) | 48.2 (12,92) |
| time between doctorate and first professorship in months (mean, standard deviation) | 102.3 (47.17) | 101.7 (48.35) | 114.7 (56.04) | 107.3 (59.30) |

Meaning of indices: a: There is a significant ($p<0.05$) gender difference within the subject; b: There is a significant ($p<0.05$) difference between the subjects within the same sub-group gender, e.g. male physicists differ from male mathematicians. Tested with T-test, Mann-Whitney-U-test and ANOVA.

Table 3 shows that the time needed to complete the doctorate was on average approximately 47 months. Male mathematicians took significantly less time than female mathematicians or physicists of both genders. Within physics, however, there was no gender difference.

Not documented in table 3 is the correlation between the time to doctorate and parenthood: female mathematicians with child(ren) or those becoming mothers while writing their doctoral thesis needed an average of three months more to finish their doctorate compared to female mathematicians without child(ren). The time to doctorate of male mathematicians was not affected by parenthood. That was not the case for male physicists who needed an average of five months more for their doctorate in the same situation. The length of time spent on pursuing a doctoral degree for female physicists was prolonged by 8.5 months on average if they had already been mothers when starting their doctorate or became mothers during the doctorate.

Looking at the time span between finishing a doctorate and first professorship it becomes apparent that mathematicians tended to need less time than physicists. But because of the relatively small number of cases these subject-related differences did not become statistically significant. This might also likely be the reason why within both disciplines neither gender nor parenthood were relevant in this context.

**Career relevant decisions during doctoral and postdoctoral phase**

The literature differentiates between reasons that are immanent to science, e.g. the strong interest in scientific work or a topic of research, and other motives for a doctorate (Enders & Bornmann, 2001; Mischau et al., 2010). Participants of our study identified interest in a specific topic as the most decisive reason for writing a doctoral thesis in both disciplines. These findings correspond with other empirical studies (e.g. Abele et al., 2004; Grotheer et al., 2012). Our data additionally revealed that in mathematics, but not in physics, significant gender differences occur concerning this intrinsic motivation. Female mathematicians classified interest in a topic as less relevant to their decision to do a doctorate than male mathematicians which sets them apart from their female colleagues in physics who did not differ from male physicists and mathematicians in this regard (see table 4).

*Table 4: Career relevant decisions concerning the doctoral and postdoctoral phase by gender and subject (in percentage)*

| | mathematics | | physics | |
|---|---|---|---|---|
| | male | female | male | female |
| doctorate out of interest in a specific topic (strongly decisive) | 75.0[a] | 53.4[ab] | 66.3 | 67.0[b] |
| doctoral thesis in the field of theoretical mathematics/physics | 50.8[ab] | 31.9[a] | 31.4[ab] | 24.9[a] |
| chose a doctoral supervisor with a high reputation in this discipline | 32.4[a] | 17.0[a] | 22.5[a] | 17.6[a] |
| institutional involvement during doctorate | 72.1 | 70.8[b] | 78.4 | 81.2[b] |
| stay abroad during postdoctoral phase | 53.1 | 54.2 | 63.6 | 60.3 |

Meaning of indices: a: There is a significant ($p<0.05$) gender difference within the subject; b: There is a significant ($p<0.05$) difference between the subjects within the same sub-group gender, e.g. male physicists differ from male mathematicians. Tested with Chi-squared test.

The choice of a certain field in the discipline and a special topic for the doctoral thesis constitute important decisions for a career in science. They are considered as a first positioning within the scientific community. Our data show that significantly more men chose the recognised theoretical field of their discipline for their doctoral thesis than women who, more often than men, did research in applied mathematics or physics as well as in the respective subject didactics. This gender difference is somewhat more obvious in mathematics than in physics and it remains constant throughout all age cohorts. When not only the topic of the doctoral thesis, but also the doctoral supervisor, can be chosen different criteria are used for assessment by the doctoral candidates. Crucial for the choice can be – and this applies to all disciplines – the supervisor’s knowledge, specialization, or personal and scientific reputation, acquaintanceship with the supervisor, sympathy etc. (Berning & Falk, 2006; Jaksztat et al., 2012). The latter criterion can be interpreted as a rather strategic decision made by 32.4 percent of the male mathematicians and 22.5 percent of the male physicists in our study. They specifically decided to look for renowned persons or institutes with good reputation for their doctorate. The comparable percentage among women in both disciplines is much lower, so divergences between the genders exist, while differences in subjects are not important for this aspect of career planning (see table 4). Cohort effects were only found in the group of the physicists. Here the youngest cohort of men and women chose the supervisor or institution on the grounds of reputation less often than all other cohorts.

The traditional or individual path to a doctorate remains the most common in Germany, especially in the social sciences and humanities. On the contrary, in the natural sciences, structured doctoral programmes are widespread. An individual doctorate requires the thesis to be produced under the supervision of a professor. This form offers a great deal of flexibility, but demands a high degree of personal initiative and responsibility, as institutional involvement is missing. Many studies show that institutional involvement (independent from the discipline) has a positive effect on the duration and the success of the doctorate (e.g. Schubert & Engelage, 2011; Jaksztat et al., 2012). Hence, institutional involvement can be considered career-enhancing. Some empirical findings in this context suggest a lower or poorer involvement of women in academic institutions compared to men (e.g. Gerhardt et al., 2005; Findeisen, 2011).

Contrary to these research results, but in accordance with the latest “Bundesbericht Wissenschaftlicher Nachwuchs” (Konsortium Bundesbericht Wissenschaftlicher Nachwuchs 2017), our sample did not reveal any gender differences, neither referring to the question whether the respondents were involved in academic life during their doctoral studies, nor how this was the case. However, the institutional involvement of young scientists seemed to be more common in physics than in mathematics. While in mathematics the cohort affiliation was irrelevant or at least did not indicate a clear pattern in the sense of a continuous change of institutional involvement of male and female young researchers over time, in physics the share of doctoral students who are institutionally involved correlates significantly with the age cohort. Many more respondents of the youngest cohort in this discipline (30 years and younger) were institutionally embedded while pursuing their doctorate than of the older cohorts. Additionally, significant gender differences in this youngest age cohort of physicists have been identified, with more women (92.8 percent) than men (85 percent) being involved in academic life during their doctorate. A similar gender effect can be observed in the youngest age cohort of mathematicians.

Academic involvement has increased in higher education since the German excellence initiative of the federal administration and the Länder to promote science and research at German universities recommended the implementation of more structured doctoral programmes comparable to those in English speaking countries. Comprehensive and reliable figures about the distribution of these programmes, their variety, and the intended improvement of the quality of mentoring and support are, however, still hard to find (Konsortium Bundesbericht Wissenschaftlicher Nachwuchs 2017).

Looking at the postdoctoral stay abroad component, more subject-specific than gender-specific differences became apparent, but because of the low numbers, these differences are not all statistically significant. Still, more physicists than mathematicians worked abroad for a longer period after finishing their doctorate. In general, parenthood seems not to have any remarkable influence on the decision for or against this career-enhancing aspect; only the female mathematicians with child(ren) in the sample were less likely to spend time abroad compared to those without child(ren). Cohort effects did not occur in any of the subject or gender groups; i.e. the share of older participants of the survey acquiring work experience abroad was comparable to younger participants.

**The application of career strategies**

Career planning serves not only to systematically set specific career goals and plan specific career steps, but to acquire professional context knowledge. Knowing the professional context and the (often) unwritten rules of an occupational field in turn represents a precondition to choosing appropriate career strategies, which have become important in working life – and in the research literature – since the late 1970s (Hall, 1976). When individuals engage in career strategies (Gould & Penley, 1984) and/or have micro-political competencies (Cornils et al., 2012), they are more likely to advance their careers. The effectiveness of a certain career strategy depends on the type of job, the nature of work in a specific field of activity, and organisational characteristics.

As organisations are gendered (Acker, 1990), the acceptance and perception of career strategies are not gender-neutral but rather shaped by gender stereotypes (Guadagno & Cialdini, 2007). "Think manager – think male", meaning that women perceive role incongruity between the female gender role and typical leader roles, also applies to the field of science and leads to two forms of prejudice: (a) perceiving women less favourably as potential leaders than men and (b) evaluating behaviour that fulfils the requirements of a leadership role less favourably when it is enacted by a woman (Eagly & Karau, 2002). Women are described as masculine and not authentic when they demonstrate typical leadership behaviour. Consequently, it is more difficult for them to become leaders or to succeed in leadership roles.

In contrast to other studies (e.g. Elprana et al., 2012), in our sample of scientists neither the advancement orientation nor leading and shaping motivation of female mathematicians and physicists working at a university or university of applied sciences was lower than for male scientists. Moreover, no differences between disciplines or age-cohorts could be found. Only the youngest cohort of male and female respondents showed a slightly lower leading and shaping motivation in both subjects than the oldest cohort. The following analyses will reveal whether or not there were similar results regarding the implementation of two selected career strategies – "(academic) visibility" and "extending work involvement".

*(Academic) visibility*

In an organisation, an employee's visibility is relevant because one's supervisor and management are made aware of one's contribution (Robbins and Coulter, 1999). In higher education visibility must occur inside the university but, more importantly, in the scientific community. This is mainly achieved by publications, which constitute a key performance criterion in appointment procedures for professorships. Some discipline-independent investigations (e.g. Schubert & Engelage, 2011) or studies focusing on STEM (e.g. Duch et al., 2013) conclude that female scientists are on average publishing less than their male colleagues. Other studies however emphasise that this difference only becomes apparent when the professional, personal and economic situation of scientists is disregarded (e.g. Prpic, 2002; Leemann, 2008).

Most respondents in our survey had already used the doctoral phase to write academic articles, although the percentage of physicists was significantly higher than for mathematicians. The data shows a similar picture regarding presenting papers at conferences. This strategic behaviour was a bit more pronounced in the early stage of the academic career of physicists than of mathematicians, while statistically relevant differences could only be found between men in both disciplines (see table 5).

Further analyses illustrated that neither gender nor having a child during a doctorate seems to affect writing and presenting at conferences for young scientists. However, we note that only the presence of and not the extent of such activities has been measured. This might also explain why our results differ from other studies, which almost consistently show lower publishing and presenting activity of women at this career level (Findeisen, 2011; Gerhardt et al., 2005; Langfeldt, 2006; Schubert & Engelage, 2011). Another explanation might reflect the most recent Elsevier-Report (2015) which indicates that female researchers in Germany tend to be less productive than their male counterparts, and that their publications have lower citation impact. But it highlights one exception: in male-dominated disciplines women publish above-average, and in informatics, physics, astronomy and engineering, women are even more productive than their male colleagues.

When analysed by subject it became apparent that significantly more male than female mathematicians focussed on building their reputation through international publications. A similar (but statistically not significant) gender difference was observed when trying to gain visibility through presentations.

*Table 5: Academic visibility by discipline and gender (in percentage)*

| | mathematics | | physics | |
|---|---|---|---|---|
| | male | female | male | female |
| writing articles during doctorate | 61.8[b] | 65.2[b] | 86.4[b] | 85.8[b] |
| presenting papers during doctorate | 77.9[b] | 85.4 | 93.5[b] | 92.0 |
| writing articles for international journals as career strategy | 53.9[a] | 28.3[ab] | 45.5 | 43.7[b] |
| presenting on international conferences as career strategy | 58.4 | 43.5[b] | 54.7 | 53.6[b] |

Meaning of indices: a: There is a significant ($p<0.05$) gender difference within the discipline; b: There is a significant ($p<0.05$) difference between the disciplines within the same sub-group gender, e.g. male physicists differ from male mathematicians. Tested with T-test, Mann-Whitney-U-test and ANOVA.

Men and women in physics did not diverge regarding the application of this career strategy and answered at the same scale level as the male mathematicians. Consequently, there were discipline differences between the two groups of women; female physicists were more strategic than female mathematicians (see table 5). Age or belonging to an age cohort might influence the relevance attached to academic visibility. Our data revealed that few young respondents regard academic visibility as a crucial strategy for their career compared to other age cohorts. The gender differences in mathematics mentioned above did not occur with the youngest cohort. Also in physics, the young female and male scientists were similar.

*Extending work involvement*

Extending work involvement represents one of seven important career strategies identified by Gould and Penley (1984). This strategy might be more relevant for professional activities in industry, because the higher education system in general has a less distinct culture of presenteeism. Consequently, only a low percentage of respondents reported much presenteeism in the workplace by working long hours: in mathematics a little more than 8 percent, and in physics close to 20 percent. This divergence of disciplines could partly be explained by experiments which are typical for (applied) physics and require close monitoring. In physics, the under 31-year-olds participants claimed to use this strategy more often than any other age groups. Because of a much stronger dependency on supervisors at the beginning of an academic career, the impact of presenteeism in the workplace is greater. Thus, this effect can be assumed to be related to age, not to cohort. Gender in both disciplines and all age cohorts did not have any impact on the application of the career strategy “work involvement”.

The academic ideal of high intrinsic work motivation usually finds expression in long working hours (among other things), regardless of where performed – at home or at the workplace.

*Table 6: Extending work involvement by discipline and gender (in percentage)*

| | mathematics | | physics | |
|---|---|---|---|---|
| | male | female | male | female |
| Showing as much presence at workplace as possible by working long hours | 6.3[b] | 9.9[b] | 19.0[b] | 20.7[b] |

Meaning of indices: a: There is a significant ($p<0.05$) gender difference within the discipline; b: There is a significant ($p<0.05$) difference between the disciplines within the same sub-group gender, e.g. male physicists differ from male mathematicians. Tested with T-test, Mann-Whitney-U-test and ANOVA.

Our study recorded average working hours per week, including overtime. Table 7 shows that there was a high variation in the group of part-time workers. Only few of them worked the contractually agreed working hours; extra work seemed to be the rule. A similar picture emerged when looking at participants who worked full-time. While the differences between male and female mathematicians were not statistically significant – neither in the group of full-time nor in the group of part-time employed respondents – the number of hours worked by female physicists was on average two hours less than those worked by male physicists.

It is always difficult to extract "pure" age effects as this variable is correlated with many other explanatory variables in statistical models. Older women of our sample, for example, were more likely to have older children, and this often implied fewer problems concerning the compatibility of family and career which in turn led to an increase in work involvement. We found a significant medium strong correlation between age and number of working hours for full-time female mathematicians: the older the participants, the more they worked. But age did not influence the working hours of male mathematicians. For part-time employed male physicists, the correlation between age and working hours was slightly negative: the older the participants, the less time they spent at work.

*Table 7: Working hours by discipline and gender*

| | mathematics | | physics | |
|---|---|---|---|---|
| | male | female | male | female |
| Part-time (mean, standard deviation) | 32.75 (8.882) | 31.88 (8.666) | 38.57[a] (12.508) | 36.21[a] (11.573) |
| Full-time (mean, standard deviation) | 48.82 (8.141) | 46.17 (11.887) | 49.60[a] (9.119) | 47.32[a] (8.771) |
| Full-time (only those with child(ren)) (mean, standard deviation) | 49.57 (8.141) | 47.04 (11.101) | 50.23[a] (9.722) | 44.67[a] (9.171) |

Meaning of indices: a: There is a significant ($p<0.05$) gender difference within the discipline; b: There is a significant ($p<0.05$) difference between the disciplines within the same sub-group gender, e.g. male physicists differ from male mathematicians. Tested with T-test, Mann-Whitney-U-test and ANOVA.

The correlation for the full-time employed male physicists was slightly positive, e.g. the older the participants, the higher the number of working hours. For women in physics the findings differed: older respondents in part-time employments invested more (weak correlation) and in fulltime employment less (medium strong correlation) time in work.

Looking at the working hours of respondents with child(ren) especially in physics we can observe an effect that is well known in other occupational groups (Lind & Samjeske 2010): men having a child increase their investment in working time while women tend to scale down their investment compared to female colleagues without children. Therefore, the gender differences already evident in the context of full-time employees were amplified by parenthood.

**PROFESSIONAL CONTRAINTS DUE TO CHILD CARE**

Careers in science are designed to have a linear and gapless progression, because good science focusing on gaining knowledge is considered a vocation, not a profession and has to be performed with dedication and passion. This myth about science assumes temporally and spatially delimited working (Graf & Schmid, 2011; Kahlert, 2013) and a continuous and output-oriented "performance culture" as well as a "presence culture" that not only includes the presence at the workplace but also at conferences and network meetings (Haghanipour, 2013; Maurer, 2016). Thus, discontinuities in the career path or restraints about related expectations of career behaviour, e.g. due to the birth of a child or child care, conflict with the normative academic ideal (Krais, 2000) of a "whole-blood and full-time scientist" that is aligned with the regular male employment biography (Rusconi & Kunze, 2015, p. 12).

Discontinuities and constraints because of family commitments can therefore have a negative effect on professional success (Graf & Schmid, 2011; Beaufaÿs, 2012; Lind, 2012). Numerous scholars have considered the myth about science and its efficacy not only as a substantial career barrier for women (e.g. Matthies et al., 2001; Lind, 2006; Haghanipour, 2013) but also as an explanation for the more common childlessness among female academics, or postponement of parenthood (Findeisen, 2011; Metz-Göckel et al., 2014;). Yet, accepting professional constraints because of children or other family commitments does not necessarily mean a lack of career knowledge. Women's career and life planning must rather be interpreted as shaped by "double socialisation" (Becker-Schmidt et al., 1983) and the struggle with complex external circumstances, such as gender stereotypes, social roles and overall cultural and societal concepts, family models, etc. (Geissler & Oechsle, 1996). In other words: "The time axis and expenditure of time of scientific careers are contradicting time axis and expenditure of time of social tasks and family commitments of all sorts in an almost insoluble way". (Maurer, 2016, p. 12) The main responsibility for the latter is still borne by women (Althaber et al., 2011; Lind, 2012).

Our empirical study is one of the first to focus on occupational constraints or renunciation due to child care for the special group of mathematicians and physicists working in the higher education system. The constraints outlined in table

8 indicate more significant gender differences than for strategic career planning or management. Women in both disciplines more often than men interrupted their employment, reduced their working hours, postponed or gave up their career goals, and reduced their participation in further training. While in physics the other constraints listed in table 8 also revealed significant gender differences, no gender differences regarding the reduction of conference participation or other career-enhancing activities due to child care could be found in mathematics.

Discipline specific differences within the group of female scientists did not occur for any of the observed types of constraint. Men differed significantly with respect to reduced participation in conferences, which was more common among mathematicians than physicists.

*Table 8: Different kinds of occupational constraints or renunciation due to child care by discipline and gender (in percentage)*

| | mathematics | | physics | |
|---|---|---|---|---|
| | male | female | male | female |
| no constraints | 18.9[a] | 2.6[a] | 26.6[a] | 3.8[a] |
| interrupted employment/career | 16.2[a] | 63.2[a] | 12.7[a] | 60.2[a] |
| temporarily reduced working hours | 32.4[a] | 57.9[a] | 36.2[a] | 62.4[a] |
| reduced participation in further training notably | 16.2[a] | 39.5[a] | 11.1[a] | 38.3[a] |
| reduced participation in conferences notably | 70.3[b] | 73.7 | 43.1[ab] | 64.7[a] |
| other career-enhancing activities (e.g. publications, networking etc.) reduced notably | 29.7 | 50.0 | 16.5[a] | 42.1[a] |
| career goals postponed | 21.6[a] | 42.1[a] | 23.5[a] | 46.6[a] |
| career goals abandoned | 5.4[a] | 21.1[a] | 7.5[a] | 13.5[a] |

Meaning of indices: a: There is a significant ($p<0.05$) gender difference within the discipline; b: There is a significant ($p<0.05$) difference between the disciplines within the same sub-group gender, e.g. male physicists differ from male mathematicians. The percentages in line 1 refer to individuals with children only. The percentages from line 2 onwards refer to those respondents with children who stated to have already had constraints due to child care in their occupational career. Tested with Chi-squared test.

From an analytical perspective – and focusing on age cohorts – the following becomes apparent: increased labour participation of women as well as the new model of active fatherhood contribute to younger men being more involved in child care and thus more often citing occupational constraints. This finding can be interpreted as an expression of societal change, especially since older cohorts of men (50 years and above) more frequently stated they had not accepted any constraints. When considering women, the comparison of age cohorts was more complex. Here signs of disintegration of traditional behavioural patterns concerning some of the aspects of occupational constraints or renunciation due to child care could also be observed. The percentage of younger mothers accepting occupational constraints was lower than the percentage of older mothers, but rarely on a statistically significant level and not equally for all aspects. This applied to both disciplines. Hence, societal change for female scientists can only be detected in our data to a much lesser extent. Instead, the assessment that a core of the maternal role remains quite consistent is confirmed, even though new elements are being added.

**EXPERIENCES WITH DISADVANTAGES REGARDING PERFORMANCE, ACKNOWLEDGEMENT AND INTEGRATION INTO NETWORKS**

Traditionally science has referred to the meritocratic concept as the ideal-typical model for distribution of resources, i.e. to the ideal of a performance-based, depersonalized evaluation of scientific work as a basis for an objective rewards system of scientific performance. Numerous studies, however, have emphasised the discrepancy between this ideal and scientific performance, the performing individual and the performance assessing environment, as well as resulting discriminatory consequences for female scientists (Krais & Beaufaÿs, 2007; Beaufaÿs, 2012). Especially in STEM disciplines, it has been shown that a gender-neutral assessment of academic achievement is an exception. Female scientists are still not perceived as competent representatives of their discipline but are being treated as members of a minority that is being assessed negatively by performance and capability traits (Kahlert & Mischau, 2000). Consequently, the "male" discipline cultures of the STEM subjects cause or reinforce gender specific attribution processes concerning professional competences as well as assessment of performance (Matthies, 2009; Graf & Schmid, 2011). Gender specific discrimination seems to increase with every qualification or status level of the academic career (Flaake et al., 2006). Experiences of little appreciation of performance and accreditation of competences by colleagues and male superiors, as described by mathematicians and physicists (Mischau & Grabarz, 2009; Mischau et al., 2010), take effect as career barriers in many ways. Especially on a subjective level, they can negatively influence "endurance" during a specific stage of the career path or the decision to continue an academic career.

Many of our respondents were experiencing disadvantages at work, especially compared to their male colleagues, concerning the appreciation of their performance and assessment of their professional competences. This discrimination indicated distinct gender differences (see table 9). Female physicists reported experiences on both these aspects significantly more often than male physicists. Within mathematics the gender differences were similar, but not statistically significant regarding performance-related discrimination. There were no significant differences between the disciplines within the gender sub-groups, i.e. the female physicists did not differ from female mathematicians.

Several studies have pointed out that female scientists on their way up the career ladder have to work harder and perform better than their male colleagues, regardless of the discipline (Krimmer & Zimmer, 2003; Majcher & Zimmer, 2008).

The female physicists and mathematicians in our survey were familiar with that kind of disadvantage compared to male colleagues and encountered a different set of requirements for their work during their career more often than male physicists and mathematicians. Differences between the disciplines did not occur (see table 9).

*Table 9: Experienced discrimination compared to colleagues by discipline and gender (in percentage)*

| | mathematics | | physics | |
|---|---|---|---|---|
| | male | female | male | female |
| recognition of performance | 20.0 | 29.4 | 18.1[a] | 40.1[a] |
| assessment of professional competence | 7.7[a] | 38.2[a] | 12.4[a] | 40.8[a] |
| external demands concerning work | 5.6[a] | 23.9[a] | 7.7[a] | 24.4[a] |
| being integrated in official information channels | 7.4[a] | 21.5[a] | 9.7[a] | 21.8[a] |
| being integrated in informal networks | 7.7[a] | 37.3[a] | 14.1[a] | 37.1[a] |

Meaning of indices: a: There is a significant ($p<0.05$) gender difference within the discipline. Tested with Chi-squared test.

Admission to and acknowledgement in the respective discipline, i.e. recognized, scientific networks and research contexts are very important to a successful career in science. Participation in networks and the associated access to information and communication structures on one hand opens, for example, “important channels to (...) be endorsed to relevant places, establish work relations and undertake research projects” (Ulmi & Maurer, 2005, p. 30). On the other hand, networks should not be underestimated as intermediaries for defined accomplishments because they and their gatekeepers “define relevant career criteria like the excellence of research projects and publications” (Sagebiel, 2016, p. 105). Establishing one´s own academic network and positioning oneself within the respective scientific community however, do not exclusively take place in formal contexts but, to at least the same extent, in the informal part of the daily scientific routine – one that is also influenced by “gendered sub-structures of academic life as hidden obstacles or opportunities for an academic career” (Maurer, 2016, p. 15).

Studies have repeatedly indicated that women are not as well integrated in formal but particularly in informal (specialised) networks (Feeney & Bernal, 2010). One reason for this is that homophile (male) structures make access to especially effective networks difficult for women (Forret & Dougherty, 2004; Rastetter & Cornils, 2012). Because of this lack of presence female scientists and their work are less visible, chances for access to career-enhancing resources are reduced (Kahlert, 2013), and the assessment of performance for a professorship is negatively influenced (Färber & Spangenberg, 2008). Discriminatory experiences relating to inclusion into official information channels and informal networks compared to male colleagues were also stated by the female participants in our study. Again, gender but not disciplinary differences could be observed, since significantly more female physicists and mathematicians experienced these disadvantages during their career than male colleagues (see table 9).

Considering age, the percentage of older respondents having encountered all the aforementioned hurdles was higher than for younger respondents. This seems to be a reference to both age and cohort effects which can hardly be separated in a cross-sectional design. On the one hand, the same effect of age can be observed for both genders, with an increased probability of experiencing discrimination at some point of the career with increased age and therefore length of working life. On the other hand, although the disadvantages experienced by women rank on a much higher level than those experienced by men and the reported gender differences are much more significant for the older respondents of both disciplines, it can be assumed that especially older cohorts of women have been confronted with considerably more traditional gender roles and stereotypes as well as stronger developed homo-social formal and informal networks than today's generation of young female scientists, and that discrimination experiences are therefore also more widespread within the older cohorts.

## CONCLUSION

The results indicate that there are more gender differences in mathematics than in physics. The data reveal that female mathematicians take longer to graduate than their male colleagues; intrinsic motivation is less often a crucial cause for graduation for women than for men; there is less institutional involvement during a doctorate; and the career strategy of academic visibility through publications in international journals is less often used by female than by male mathematicians. These gender disparities between the disciplines can have a negative influence on the career and success of female mathematicians compared to female physicists and might therefore – at least on the individual level considered here – provide a possible explanation for why the exhaustion of the female scientific recruiting potential is still less successful for mathematics than for physics in Germany. Whereas experiences of disadvantage in the workplace regarding the recognition of accomplishments, attribution of professional competencies, external demands from work as well as the integration in official information channels and informal networks continue to be a cross-disciplinary phenomenon caused by the gender differentiating academic culture, they do not provide a reasonable explanation for divergences regarding the leaky pipeline in mathematics and physics. They do however explain gender disparities in success in academic careers in general. The same applies to the mainly traditional gender arrangements of scientists in relation to parenthood. More female than male academics in both disciplines accept constraints or abandon career goals due to child care despite better career knowledge. At the same time, this is one of the areas where analyses by age cohort clearly indicate a slight change.

To summarize our results: we see indications of a reduction in gender disparities in both disciplines, e.g. related to some aspects of career relevant decisions or leading and shaping motivation, as well as clear persistence of gender-related differences, e.g. in terms of discrimination or "motherhood as a career risk". Further (gender-sensitive) change in the way academic careers develop can best be measured by the degree of abolition of generative discrimination in higher education (Metz-Göckel et al., 2014). How the changes emerging in a few places in the youngest cohort of our study – presumably caused by increasing structuring of training for doctoral students and changes of the legal framework in Germany – will affect equal opportunities for men and women in academia, only future research will show.

## ENDNOTES

[1] Only degrees of mono master studies and former diploma studies (before the Bologna reform) were chosen as reference group in the following text, since these are considered the "classic" recruiting potential for an academic career. The inclusion of graduates of teacher training would create distortion for the description of retrospective analyses of career courses or subject specific leaky pipelines.

[2] The project was funded by the German Federal Ministry of Education and Research (BMBF) and the European Social Fund of the European Union (ESF).

[3] Given that the percentage of individuals graduating late is much higher in the group of women, comparing mean values to display the difference in genders is not applicable here as it would distort the result.

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