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安徽工程大学

Anhui Polytechnic University

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题目　《神经科学原理》（第三十四章）英汉翻译实践报告

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专业学位类别　翻译硕士

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A Report on the E-C Translation Practice of *Principles of Neural Science* (Chapter 34)

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A Report on the E-C Translation Practice of Chapter 34 of *Principles of Neural Science*

Ding Xiaoxuan

A thesis submitted in conformity with the requirements

For the degree of Master of

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In English Translation

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摘 要

本次翻译实践选材于《神经科学原理》第五版。该书由坎德尔领衔主编，是国际上最权威的神经科学教科书。全书共 67 章，涵盖了整个神经科学领域，全面系统地诠释了脑是如何控制全身各器官系统功能以及适应环境的行为的。此书为各类神经科学工作者和学生提供了一个极有价值的指南，并且，该书目前尚无中文译本正式出版，因此十分适合作为此次翻译实践的文本。译者选取第三十四章《运动单位与肌肉活动》作为翻译文本，主要内容包括：运动单位是控制肌肉的基本单位、肌力取决于肌肉结构、不同运动需要不同的活动策略。源文本结构严谨，专业性强，具有词形复杂和句式复杂的特征，专业术语、抽象名词、缩略词普遍存在，复合句和被动句广泛应用。

在翻译过程中，词义的准确和通顺、句式的转化、篇章逻辑的显化是此次翻译实践中遇到的几大难点。针对大量专业术语，利用联立关系、专业领域和语境确定词义。对于普通词汇，通过转换词性突破原文的句式，引起句法的转换。面临科技英语复杂长句，根据时序原则、因果原则和范畴原则，调整语序。为了加强译文整体的逻辑性和连贯性，加强段落与图的联系，对原文结构进行适当调整和补充。

本次翻译实践过程中，译者查询了许多相关领域的平行文本，因此对神经科学有了更深入的理解。译者对科技类文本的翻译能力得到了显著提升，不仅掌握了大量专业术语，提高了语言表达和逻辑思维能力，还丰富了翻译技巧，并熟练运用翻译软件和工具，从而提高了翻译的准确性和效

率。译者也认识到“跨专业＋翻译”的重要性，对译者今后的职业发展具有积极意义。最后，译者希望本次翻译实践能为神经科学领域的初学者或专业人士提供借鉴和参考。

关键词：《神经科学原理》；术语确定；词性转换；语序调整；显化逻辑；语篇连贯

Abstract

The materials for this translation practice are selected from the fifth edition of *Principles of Neural Science*, which led by Eric R. Kandel and is the most authoritative neuroscience textbook internationally. This book consists of 67 chapters, covering the entire field of neuroscience and comprehensively explains how the brain controls the functions of various organ systems throughout the body and how to adapt to the environment. It provides a valuable guide for all neuroscience workers and students, and there is currently no officially published Chinese translation, making it very suitable as a text for this translation practice. The translator selected Chapter 34 (The Motor Unit and Muscle Action) as the source text, which mainly includes: The Motor Unit is the Elementary Unit of Motor Control, Muscle Force Depends on the Structure of Muscle, and Different Movements Require Different Activation Strategies. The source text is rigorous in structure and strong in professionalism, featuring complex word forms and sentence patterns. It commonly incorporates technical terms, abstract nouns, and acronyms, and widely applies complex sentences and passive voice constructions.

During the translation process, the main challenges encountered include the accuracy and fluency of word meanings, the conversion of syntactic patterns, and the clarification of textual coherence. For a large number of technical terms，word meanings were determined based on collocation relationships, professional fields, and context. For common vocabulary, word-class transformation was employed to transcend the original sentence structures, resulting in syntactic shifts. Facing complex and long scientific English sentences, the order of words was adjusted according to principles of temporal sequence, causality, and scope. To enhance the overall logic and coherence of the translation, the connection between paragraphs and diagrams was strengthened, and appropriate adjustments were made to the original structure.

During this translation project, the translator has referred to many parallel texts in relevant fields, thereby gaining a more thorough understanding of neuroscience. The translator’s proficiency in translating scientific texts has significantly improved, not only by mastering a vast array of technical terms, but also by enhancing language expression and logical thinking skills. Additionally, the translator has expanded her repertoire of translation techniques and become adept at using translation software and tools, improving the accuracy and efficiency of the translation process. Meanwhile, she recognized the importance of “cross-discipline plus translation,” which holds positive implications for her career development. Ultimately, the translator hopes that this translation practice will serve as a useful reference for both beginners and professionals in the field of neuroscience.

Key Words: *Principles of Neural Science*; technical term determination; part-of-speech conversion; adjustment of sentence order; externalization of logic; discourse coherence

Contents

Chapter 1 Task Description

1.1Background of the Practice

The materials for this translation practice are selected from the fifth edition of *Principles of Neural Science*, which edited by Eric R. Kandel and co-authored by several neuroscience gurus. It is the most authoritative neuroscience textbook internationally and often referred to as the “Neuroscience Bible”. This book provides a valuable guide for all neuroscience workers and students, and there is currently no officially published Chinese translation, making it very suitable as a text for this translation practice. The translator collaborated with schoolmates to translate different chapters, and she was responsible for Chapter 34, with a total of 11762 words in the source text and 16368 words in the translation, which meets the requirement for the word count in a master’s translation report.

1.2Source of the Task

Principles of Neural Science covers the entire field of neuroscience, and gathers the main and latest research of many authoritative neuroscientists. From the molecular, cellular, and anatomical structures of the nervous system to sensory, motor, and cognitive functions, it comprehensively explains how the brain controls all the organ systems and adapts to the environment. Each chapter introduces the main principles and important mechanisms in the corresponding subfield, providing a valuable guide for neuroscientists and students. The main content of Chapter 34 *The Motor Unit and Muscle Action* includes: The Motor Unit is the Elementary Unit of Motor Control, Muscle Force Depends on the Structure of Muscle, and Different Movements Require Different Activation Strategies.

1.3Significance of the Practice

Firstly, the translation practice could expand knowledge in neuroscience. The source text embodies the main and latest research of many authoritative neuroscientists, systematically interpreting the basic knowledge of neurobiological sciences. During this translation practice, the translator accumulated many professional terms and learned a lot by searching parallel texts, referring to relevant background knowledge, and consulting professionals.

Secondly, the translation practice could improve translation skills. The source text is professional and scientific, perfectly aligning with the basic characteristics of technical texts. Through this practice, the translator has become adept at applying specialized techniques for scientific English translation, accumulated experience in translating scientific texts, and improved the ability to translate scientific English. On the other hand, the translator has mastered several CAT softwares. The application of CAT in translation is becoming increasingly widespread, and proficient use of various CAT tools has become an indispensable and important skill for translators. They helped the translator increase efficiency, enrich her terminology and corpus, and have a positive impact on her future translation practice and career development.

Thirdly, scientific and technological literature is the foundation for both the public and professionals to access scientific knowledge. It is also a carrier and tool for the spread of knowledge and advanced technology. Without high-quality translation in scientific English, effective scientific communication is not possible, making the importance of scientific English translation clear (郑淑明, 曹慧, 2011: 17). *Principles of Neural Science* is known as the "Neuroscience Bible", providing a valuable guide for neuroscientists and students. The translator hopes to provide reference and convenience for more professionals and those interested in it.

Chapter 2 Pre-translation Preparations

Pre-translation preparation is an indispensable part of the translation process, which directly affects the efficiency and the quality of the work. By gaining a deep understanding of the original content, mastering professional knowledge and skills, translators can ensure the accuracy and professionalism of translation. Meanwhile, by understanding the needs and background of the target reader, translators can more accurately grasp the style and content of the translation, making the work more in line with the expectations of the readers.

2.1 Analysis of the Source Text

Peter Newmark categorizes texts into three main types: expressive, informative, and vocative. Different methods, namely semantic and communicative translation, should be employed for each text type (Peter Newmark, 1981). The *Principles of Neural Science*, rigorous in structure and strong in professionalism, elaborates intricate concepts in neurobiology, as well as the structure and operations of the nervous system. Thus, it is the informative text.

The core of informative texts is “authenticity”. When translating, communicative translation should be adopted, which aims to “accurately convey the contextual meaning in a way that is easily accessible and understandable to the target reader, both in terms of thought content and language form. The source text features intricate sentence structures, and rigorous logic. It commonly incorporates technical terms, abstract nouns, and acronyms, and widely applies complex sentences and passive voice constructions. The target reader extends beyond students and researchers in neuroscience and may include readers with a profound passion for the field. Therefore, during the translation process, the translator must consider how to render the text smoothly and clearly, avoiding any obscurity or difficulty for the reader to understand. This is also the key challenge and focus of this translation practice.

2.2 Translation Auxiliary Tools

Appropriate computer-aided translation tools can greatly improve translation efficiency, especially for projects that require processing large amounts of text. CAT also have certain proofreading functions. After revising the translated text, preserve the modified version to a new translation memory and terminology database, allowing the database to have a larger reserve of resources for translators to reference and use.

Choosing tools that can provide professional terminology and industry standards can ensure the quality of work. Due to the large number of neurobiological terminology in the source text, the translator chose *The World Contemporary English-Chinese Neuroscientific Dictionary*, *Xiangya Medical Dictionary*, and Term Online (a standardized terminology service platform sponsored by the China National Committee for Terms in Sciences and Technologies) as translation aids, and created a glossary using Snowman CAT software.

After preliminary translation practice, the translator has become proficient in using memoQ. Therefore, she still chooses it as the main CAT software, continuously updating the termbase and enriching her corpus during the translation process.

At last, since the translator lacks background knowledge in neuroscience, she has consulted relevant parallel texts and reference books to focusing on the writing style of such texts, and learned relevant background knowledge to help accurately understand the original content and improve the accuracy of translation.

2.3 Parallel Text

Parallel texts refer to original texts and their translations placed side by side for comparative reading. Collecting numerous parallel texts and organizing them according to certain standards forms parallel corpora. These materials can include thematic articles, encyclopedia entries, and even dictionary definitions and examples. In a broader sense, parallel texts also encompass translated materials similar to the original content, primarily used for deeper understanding. Simply put, parallel texts are any reference materials closely related to the original content (李长栓, 2009, 91).

When encountering an unfamiliar field or overly specialized translation content, searching for parallel texts can help locate authentic or professional translations, acquire domain-specific knowledge, and learn the writing style of the field. However, it does not mean they can be directly used; translators must carefully read the words and sentences they find, compare them with the content that needs to be translated, and select the translation they need. For the translator who does not have a background in neuroscience, translating scientific and technological texts may present multiple challenges: highly specialized terms, complex sentence structures, rigorous logical arguments, and authentic Chinese expressions. In such cases, reading professional literature and books related to the source text content, and studying the expression of similar Chinese texts, can enhance the professionalism of translation works. The translator searched for relevant parallel texts based on keywords and neuroscience field, including *Principles of Neural Science* (2nd Edition), *Physiology of Sport and Exercise* (3rd Edition), and *Principles and Practice of Resistance Training*. The rigorous logical structure, clear expression, and professional terms in these texts have set the translation standard. The translator strived to maintain a writing style consistent with the parallel texts, ensuring both the professionalism and readability of the translated text. Furthermore, comparing source and parallel texts reveals key term definitions and translations, crucial for the overall translation quality.

2.4 Glossary Building

The translator used Snowman Computer Assisted Translation Software to create a glossary. The original text contains a large number of specialized terms in neurobiology. Before translating, the translator first lists the terms and entries in the original text, and then uses dictionaries and parallel text to verify their translation, unifying the expression of terms. The translator found that Professor Han Jisheng edited the second edition of *Principles of Neural Science* in Chinese, with a professional vocabulary index and a comparison table of professional vocabulary in both Chinese and English at the end of the book. In addition, chapters 1-4 have been translated by the translator's schoolmates and the termbase has been shared. Simultaneously, collaborative discussions were held with team members to standardize technical terms, ensuring that the translations were consistent, complete, and free from errors. Consequently, a comprehensive list of terms and proper nouns was established, which can be found in Appendix I. When translating, the translator continuously updated the terminology database using multiple authoritative terminology platforms such as CNKI and TermOnline.

Chapter 3 Case Study

3.1 Achieving Accuracy and Fluency of Lexical Meaning

Scientific writing conveys objective truths and facts, requiring precision in professional terminology. These terms, as conceptual nouns in specific fields, are limited to their respective professions, with fixed forms, single meanings, and low potential for confusion. Across domains, technological terminology exhibits a clear semantic hierarchy, conciseness, stability, and international recognition (韦孟芬, 2014: 6)

Beyond these terms, scientific writing employs a wealth of common vocabulary, including both content words and grammatical function words (e.g., prepositions, articles, conjunctions). However, in this context, these words' meanings differ from their everyday usage, being tailored to the expression of objective phenomena and concepts. Thus, their translation in scientific text merits special attention.

3.1.1 Determining the Meaning of Technical Terms in Neuroscience

Accurate understanding the meaning of words is a crucial step in the translation of scientific English. Once there is a deviation in the understanding of vocabulary, especially key terms, the translation quality of the entire scientific article will be greatly affected.

This chapter contains a large number of neurobiological terms, and the translator verifies their translations through Term Online, *Xiangya Medical Dictionary*, *the World Contemporary English-Chinese Neuroscientific Dictionary*. However, there are still some terms that cannot be accurately translated. The translator determined the meaning of words mainly from the following three aspects: ① The collocation relationship of vocabulary. The meaning often depends on its collocation with other words. Taking universal as an example, it has different meanings in different collocation relationships, such as heavy crop - 大丰收, heavy current - 强电流 (张治英, 1999: 11); ② the professional field; ③ the context. In addition, the translator also referred to the parallel texts to identify translations or definitions that correspond to the professional terminology in the original text.

Example 1

Source Text (ST): Sarcomeres are connected to one another and to the muscle fiber membrane by the **cytoskeletal lattice**.

Target Text (TT): 肌节相互连接，并与肌肉纤维膜通过**细胞骨架**相连。

Analysis:

In Example 1, the difficulty of translation mainly lies in the neurobiological term "*cytoskeletal lattice*", whose Chinese equivalent term could not be got directly through dictionaries and online terminology data base. Then the translator searched for relevant literature through CNKI, but was unable to confirm the accurate translation. The translator enquired about the two words separately to find similar entries.

According to *the Xiangya Medical Dictionary*, the word "*cytoskeletal*" means "*细胞支架的, 细胞骨架的, or 骨架*", with similar entries as "*cytoskeletal filament 细胞骨架细丝*". It is a network structure composed of fibers such as microtubules, microfilaments, and intermediate filaments, which forms an ordered arrangement within the cell, similar to a grid or lattice-like structure. The word "*lattice*" basically refers to "*网格*" or "*晶格*". In the neurobiology, it refers to the grid structure of protein fiber in the cytoskeleton, including microtubules, microfilaments, and intermediate filaments. These fibers form an orderly arrangement within the cell, supporting cell shape and function. Apparently, the two words "*cytoskeletal*" and "*lattice*" both refer to an ordered arrangement within the cell. In order to avoid repetition and confusion, the shared meaning of the two words was retained and the term "*cytoskeletal lattice*" was translated into "*细胞骨架*" in example 1.

Additionally, in scientific discourse, it is common to find the repetition of terms with the same or similar meanings. These terms complement each other semantically, contributing to the coherence and enhancing the expressive effect of the discourse (杨双, 2014:107). From the following sentence "*The cytoskeleton influences the length of the contractile thick and thin filaments…*", it can be implied that "*The cytoskeleton*" and "*cytoskeletal lattice*" are different expressions of the same meaning. Ultimately, "*cytoskeletal lattice*" was translated into "*细胞骨架*".

Example 2

ST: The response to a single action potential is known as a **<u>twitch contraction</u>.**

TT1: 对单个动作电位的反应称作**<u>抽动收缩</u>**。

TT2: 由一个动作电位引起的收缩称作**<u>单收缩</u>**。

Analysis:

The difficulty of Example 2 is the accurate translation of the term "*twitch contraction*". In TT1, it was translated into "*抽动收缩*" by combining the meanings of the words "*twitch*" and "*contraction*". However, when proofreading, the translator noticed that both "*twitch contraction*" and "*twitch*" appeared multiple times in the original text, and the translation in TT1 fell short in terms of semantic coherence and fluidity. More importantly, this translation did not align closely enough with the definition provided in the ST.

To capture the information from the original text more accurately, the translator revisited the relevant paragraphs of the original text and discovered a similar expression: "*A rapid series of action potentials elicits superimposed twitches known as a tetanic contraction or tetanus*". By summarizing the main idea of the section containing these two sentences, namely that the type of muscle contraction is determined by the number and frequency of action potentials, the translator decided to refer to relevant literature and adopt a more precise translation strategy.

To this end, the translator used keywords such as "*muscle contraction, twitch contraction, tetanic contraction* and *tetanus*" to search for parallel texts and research the explanations of terms. Referring to the mechanical characteristics of muscle contraction in *Physiology of Sport and Exercise*, the translator learned that there are two forms of skeletal muscle contraction: *单收缩* and *强直收*缩. When a skeletal muscle or single cell is stimulated by a brief impulse, the stimulated cell generates an action potential, followed by a contraction and relaxation, which is called *单收缩*. When the frequency of continuous stimulation reaches a certain level, the muscle remains in a state of continuous contraction, producing superimposed twitches, which is *强直收缩* (邓树勋, 2015: 25). By comparing, the two definitions were highly consistent with the description of "*twitch contraction*" and "*tonic contraction*" in the original text. Consequently, the terms "*twitch contraction*" and "*tonic contraction*" were translated into "*单收缩*" and "*强直收缩*", which has been verified by experts and met with approval. This modification not only enhanced the conveyance of the original meaning but also increased the applicability and accuracy of the translated text in the professional field.

3.1.2 Converting Parts of Speech

The distinct thinking patterns and cultural backgrounds between the East and the West necessitate unique expression forms in English and Chinese. This is initially reflected in the disparity of word usage between the two languages—Chinese favors verbs, endowing it with a dynamic quality; whereas English tends towards nouns, adjectives, and other static parts of speech, characterizing it as a static language.

Halliday pointed out that nominalization is the most obvious form of grammatical metaphor, especially in scientific texts (Halliday, 1994: 352). The common structure is "nouns (denoting actions) + of + nouns + modifiers", which often serves as a subordinate clause, avoiding excessive use of the subject-predicate structure, resulting in concise writing, objective expression, precise and informative. Meanwhile, it emphasizes the fact rather than the action. When translating, consideration should be given to the differences in static and dynamic advantages between English and Chinese. The subject-predicate relation can be restored based on logical semantics, and such noun phrases can be expanded into clauses with subject-predicate structures.

Furthermore, the nominalization in English leads to the extensive use of prepositions, resulting in a prepositional predominance. When combined with a noun predominance, this reinforces the static tendency of the English language. Many English sentences often express actions through prepositions, however, they are rarely used in Chinese. So, when translating from English to Chinese, it is necessary to translate English prepositions and prepositional phrases into Chinese related verbs.

Given the structural and expressive differences between English and Chinese, it is essential to modify sentences and discourses by employing word-class conversion to break the constraints of the original word and sentence structure, transforming many awkward and rigid expressions into more fluent and natural ones (郑淑明，曹慧, 2011: 19).

Example 3

ST: This results in **the release of** P_i and **the extension of** the myosin neck, ……

TT1: 上一步导致 P_i**的释放**以及肌球蛋白颈**的扭动**，……

TT2: 上一步导致 P_i**被解离**，肌球蛋白颈向桥臂方向**扭动**，……

Analysis:

In Example 3, the main focus is on the two nominalization structures —— "*the release of P_i*" and "*the extension of the myosin neck*". Chinese, as an action-driven language, tends to use verbs to express the states and processes of things. To conform to the habits of the target language. The subject-predicate structures were restored—— "P_i is released" and "the myosin neck extends".

Example 4

ST: **The consequence of** this organization is that the force exerted by the contractile elements in a sarcomere can be transmitted along and across sarcomeres (through desmin and skelemin), within and between sarcomeres (through nebulin and titin), and to the costameres.

TT1: 这种组织结构的**结果是**，肌小节中收缩元件施加的力可以通过结蛋白和骨骼蛋白沿着肌小节传递并穿过肌小节，通过伴肌动蛋白和肌连蛋白在肌小节内和肌小节之间传递，以及传递到肋节。

TT2: **有了**这样的组织结构，肌小节中收缩元件施加的力可以通过结蛋白和骨骼蛋白沿着肌节传送并穿过肌小节，通过伴肌动蛋白和肌连蛋白在肌小节内和肌小节之间传送，还可以传送至肋节。

Analysis:

The focus of Example 4 lies in "*The consequence of*". TT1 adopts a direct translation approach, preserving the structure and wording of the source sentence, while TT2 uses a method of free translation, rendering it as "*有了……*".

In terms of contextual adaptability, "*有了……*" is commonly used in Chinese to introduce a condition or cause, followed by an explanation of the resulting effect or change. This expression aligns more closely with the Chinese habit of describing causal relationships, making the logic of the sentence clear and easily comprehensible. When describing the relationship between the organizational structure of sarcomeres and their function, "*有了……*" accurately conveys that this structure is the condition or foundation that enables force transmission. It emphasizes the importance of the organizational structure, rather than merely indicating a result. Although "*结果是*" can also express the outcomes brought about by the structure, it does not explicitly point out that this result is based on a specific structural foundation.

From the information fluidity, the use of "*有了……*" at the beginning sets the stage for the following information, making the entire sentence flow more smoothly in its narrative. This expression helps readers form expectations while reading, thus better receiving and understanding the subsequent information.

Culturally, Chinese tends to start with reasons or conditions when describing things, then lead into results. This mode of thinking resonates with the expression "*有了……*". In contrast, "*结果是*" leans more towards the linear thinking common in Western culture, directly stating problems and answers without emphasizing the process.

In summary, "*有了……*" is more suitable than "*结果是*", as it helps readers better understand complex scientific information and enhances the overall readability of the text.

Example 5

ST: The sliding of the thick and thin filaments is triggered by the release of Ca^{2+} <u>**within**</u> the sarcoplasm of a muscle fiber in response to an action potential <u>**at**</u> the fiber's membrane, the sarcolemma.

TT1: 粗肌丝和细肌丝的滑行是由肌纤维肌浆<u>**内**</u>钙离子的释放引起的，以响应肌纤维膜（肌膜）<u>上</u>的动作电位。

TT2: 动作电位<u>**到达**</u>肌纤维膜（肌膜）后，钙离子<u>**进入**</u>到肌纤维肌浆，触发了粗细肌丝相互滑行。

Analysis:

The difficulty of Example 5 lies in presenting the dynamic biological process described in the ST to Chinese readers while preserving the original meaning.

In addressing the prepositions "*within*" and "*at*", TT1 employed "*……内*" and "*……上*"

to express the specific position. While in TT2, they were translated into verbs "*进入*" and "*到达*" respectively, based on Chinese expression habits and a profound understanding of the sliding filament hypothesis as mentioned in Example 7. In Chinese, verbs can directly express changes in actions or states, which differs from using prepositions in English to express dynamics. Specifically, "*within*" conveys not only a spatial extent but also implies a dynamic process, i.e., Ca^{2+} being released into the sarcoplasm from the sarcolemma. Therefore, translating "*within the sarcoplasm*" as "*进入肌浆*" more accurately conveys this dynamic process. Similarly, "*at the fiber's membrane*" not only indicates the location of the action potential but also implies the process of its conduction, that is, the action potential is rapidly transmitted through the axon to the sarcolemma. Using verb "*到达*" can better represent this dynamic transmission process.

3.2 Shifting Syntactic Structures

The sentence structure of scientific English is usually complex, with many long sentences, so the translation often involves word order adjustment. Differences in word order are caused by differences in the order of thinking. The thinking order in Chinese follows three basic principles: ① Temporal sequence. Sort events in the order they occurred; ② Causality. The reason is first, then the result, or the condition first, then the result; ③ Categorical principle. It helps us better understand and organize concepts in language by categorizing similar things into the same category, thereby making expression clearer and more accurate (傅勇林, 唐跃勤, 2011: 112).

Specific methods include segmentation, amplification, and abridgment. Segmentation involves altering the structure of the original sentence, extracting certain components from their original structure, and translating them into one or more independent components or sentences. Amplification involves adding essential words, phrases, clauses, or entire sentences to the original text to align the translation with Chinese grammatical and stylistic norms, as well as to preserve the original's rhetoric, grammatical structure, meaning, and tone. This addition is not arbitrary but rather involves incorporating implied meanings from the source text that are not explicitly stated (李银芳, 2007: 19). Due to the differences in syntactic structure and word usage between English and Chinese, words that are necessary in English may not be required in Chinese sentences. In such cases, the principle of omitting words without omitting meaning can be applied (陈刚，杨春华, 2011: 69).

3.2.1 Adjusting Temporal Sequence

The adjustment of word order is particularly important in long sentences with multiple nested meanings in scientific English. When translating, translators need to consciously break through the constraints of the original structure, first identify the central content and meanings of the entire sentence, then analyze the logical relationship between the meanings of each layer, and then rearrange and process the word order according to Chinese thinking habits and expression methods.

Example 6

ST: The improvement in contraction speed① **caused by** strength training②, for example, is associated with an increase in the maximal shortening velocity of a muscle fiber③ **caused by** the enhanced capabilities of the myosin molecules in the fiber④.

TT1: 例如，力量训练**引起的**收缩速度的提高与纤维中肌球蛋白分子能力增强**引起的**肌肉纤维最大缩短速度的增加有关。

TT2: 例如，通过力量训练②，纤维中肌球蛋白分子能力增强④，加快了肌纤维最快缩短速度③，从而加快了收缩速度①。

Analysis:

In Example 6, the difficulty of translation mainly lies in how to handle the two adverbial reasons introduced by “*caused by*”. In TT1, retaining the original sentence structure leads to an ambiguous and confusing translation, thereby affecting the reader’s comprehension of the entire sentence’s meaning.

By searching for relevant literature, the translator clarified how strength training can improve muscle properties and improve athletic performance: Strength training → Increased muscle strength → Enhanced ability of myosin molecules during contraction → Accelerated maximal shortening velocity of muscle fibers, that is, muscle fibers can complete more contractions per unit time → Significant improvement in overall muscle contraction speed. According to the principle of temporal sequence, the translator restructured the word order from ①②③④ to ②④③①, thereby accurately depicting the process. The long sentence is divided into several short sentences, which makes it more fluent and understandable to read.

Example 7

ST: The sliding of the thick and thin filaments① is triggered by the release of Ca^{2+} within the sarcoplasm of a muscle fiber② in response to an action potential at the fiber's membrane, the sarcolemma③.

TT1: 粗肌丝和细肌丝的滑行①是由肌纤维肌浆内钙离子的释放②引起的，以响应肌纤维膜上的动作电位③。

TT2: 动作电位到达肌纤维膜后③，钙离子进入到肌纤维肌浆②，触发了粗细肌丝相互滑行①。

Analysis:

The language form, mode of expression, and syntactic structure of ST are mechanically transplanted into TT1, thus creating a language hybrid that does not conform to the expressive habits of the target language. The emphasis of Example 7 is to eliminate the translationese and make the translation natural and smooth. In context, ST is describing the triggering mechanism of the sliding of muscle fibers, and the translator has gained a detailed understanding through the *Principles and Practice of Resistance Training*.

When the action potential reaches the muscle fiber membrane, it causes a change in the membrane potential. This change leads to the depolarization of the muscle cell membrane, causing the calcium release channels of the sarcoplasmic reticulum (SR) to open, releasing the Ca^{2+} stored in the SR into the sarcoplasm. The Ca^{2+} binds to the calcium binding sites on the troponin, causing a conformational change in the troponin, allowing it to bind to the myosin head, forming a troponin-tropomyosin complex. These complexes move in the sarcoplasm, causing the thick filaments to slide on the thin filaments (Sands et al, 2017: 33). Following above process, the translator reorganized the language order according to the sequence: ③ action potential → ②Ca^{2+} → ①sliding of thick and thin filaments Additionally, the translator also converted noun phrases and prepositions in the source text into verbs (for details, see section 3.1.2).

3.2.2 Manifesting the Implicit Causality

Causality is the most common and crucial logical relationship in scientific and technological English, with common forms such as "because, so, since, for, due to" etc. The expression habits in Chinese are generally to follow the order of cause and effect. However, causality is not confined solely to these expressions; in many instances, it's embedded within the inherent logical connections. Therefore, translators not only needs to translate explicit causality well, but also have to discover and handle implicit logic (谷青松, 2015: 7).

3.2.2.1 The Conjunction "And"

The primary meaning of "and" is to indicate coordination relation. Beyond this, it also encompasses various other implications, including implicit causation.

Example 8

ST: As sarcomere length decreases **and** the overlap of the thick and thin filaments increases (between lengths a and b), the force increases **because** the number of cross bridges increases.

TT1: 随着肌节长度变短**和**粗细肌丝的重叠部分增加（在长度 a 和 b 之间），力增加，**这是因为**横桥的数量增加。

TT2: **由于**肌节长度变短，粗肌丝和细肌丝的重叠部分增加（在长度 a 和 b 之间），横桥数量也随之增多，**因此**力变大。

Analysis:

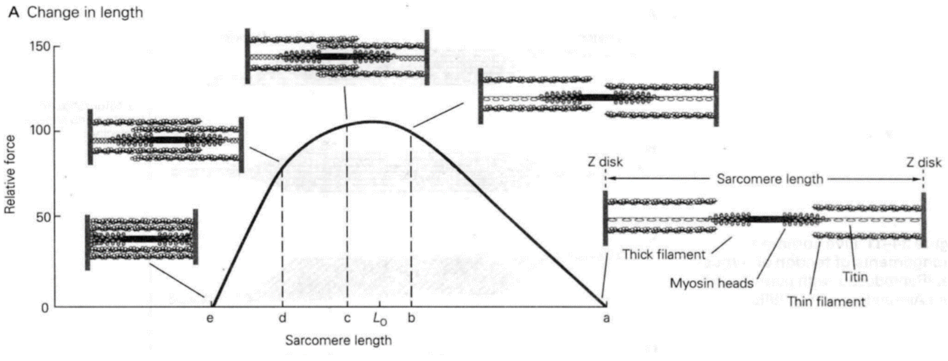

Figure 1

In Example 8, the difficulty mainly lies in the conjunction "*and*", as its underlying implicit logic might be overlooked. It is unclear whether "*and*" signifies "*和*" or "*所以*". But based on Figure 1, it can be observed that the increase in the overlapping region is a result of the decrease in sarcomere length, indicating that "*and*" in this instance functions as "*所以*". Therefore, in TT2 the translator added "*由于*" to explicitly clarify the implicit causal relationship. At last, adhering to the principle of causality, the translator placed "*the force increases*", which represents the result, at the end of the sentence.

Example 9

ST: When a muscle is stretched while in this state, such as would occur during a postural disturbance, muscle stiffness enhanced, **and** the muscle is more effective at resisting the change in length. This property is known as *short-range stiffness*.

TT1: 当肌肉在这种状态下被拉伸，例如在姿势平衡障碍的情况下，肌肉刚度增强，肌肉更有效地抵抗长度的变化。这一特性叫做*短程刚度*。

TT2: 当肌肉在这种状态下被拉伸，例如在姿势平衡障碍的情况下，肌肉刚度增强，**这使得**肌肉更有效地抵抗长度的变化。这一特性叫做*短程刚度*。

Analysis:

The challenge of Example 7 lies in identifying and manifesting the implicit causal relationship. The phrase "*muscle stiffness*" refers to the muscle's ability to resist deformation. When it enhances, under the same external force, the muscle's length changes less, that is to say, the muscle's resistance to length changes improves. Therefore, the conjunction "*and*" in example 7 implies a causal relationship. The translator added the conjunction "*这使得*" in TT2 to explicitly manifest the causal relationship.

3.2.2.2 Verbs, Adjectives, and Nouns

Some English verbs (including verb phrases), adjectives (including adjective phrases), and nouns (including phrases composed of nouns and others) also imply causal relationships, such as "make", "cause", "be responsible for", "the result" and so on. When translating sentences containing such words, one should also strive to clearly express the implicit causal relationship in the original text, to be faithful to the original text (黄湘, 2002: 18).

Example 10

ST: These properties are assessed by examining the force exerted by individual motor units **in response to** variations in the number and rate of evoked action potentials.

TT1: 单个运动单位**对**诱发动作电位的数量和速率变化**做出反应**，从而施加一定的力，该运动单位的属性就是通过检验这种力来评估的。

TT2: **由于**诱发动作电位的数量和频率发生变化，单个运动单位**才**施加一定的力，通过检验这种力，评估该运动单位属性。

Analysis:

The difficulty of Example 8 lies in the causal relationship implied by the phrase "*in response to*". Its basic meaning is "*对……做出反应/答复*". *A,* in response to *B*, which indicates that *A* reacts because of *B*. Consequently, the phrase "*in response to*" can express causal logic, and its meaning can be expanded as "*引起，造成，是引起……的原因，由于……才*". ST was rewritten as "*the force was exerted by individual motor units because the number and rate of evoked action potentials variate.*" Meanwhile, the translator adjusted the word order, placing the cause before the effect.

Example 11

ST: Similarly, the increase in maximal force **is associated with** the enlarged size and increased intrinsic force capacity of the muscle fibers produced by an increase in the number and density of the contractile proteins.

TT1: 同样地，收缩蛋白数量和密度的增加导致肌肉纤维变大和内在动力增强，最大力的增加**与其有关**。

TT2: 同样的，收缩蛋白的数量和密度增加，肌纤维就会变大，其内在动力增强，**那么**，最大力也会增加。

Analysis:

The difficulty of Example 11 lies in the phrase "*is associated with*". It can express two types of relationships: one is correlation, and the other is causation. In the ST, "*the enlarged size and increased intrinsic force capacity of the muscle fibers*" is the cause, and "*the increase in maximal force"* is the effect. In TT2, the Chinese expression "*那么*" is used to clearly show the causal relation between the two parts.

3.2.3 Adding Category Words

Adding category words means generalizing the listed items with categorical terms, making the translation clearer and more explicit (陈刚, 杨春华, 2011: 69).

Example 12

ST: At the level of the muscle, the functional attributes of the fibers are modified by the orientation of the fascicles to the line of pull of the muscle and the length of the fiber relative to the muscle length.

TT1: 在肌肉层面，纤维的功能属性通过相对于肌肉牵拉线的肌束方向和相对于肌肉长度的纤维长度来改变。

TT2: 在肌肉层面，纤维的功能属性**受以下两个因素影响：**一是相对于肌肉牵拉线的肌束方向，二是相对于肌肉长度的纤维长度。

Analysis:

Overall, ST can be divided into two parts:

① At the level of the muscle, the functional attributes of the fibers are modified……

在肌肉水平上，纤维的功能属性通过……和……来改变。

② ……by the orientation of the fascicles to the line of pull of the muscle and the length of the fiber relative to the muscle length.

相对于肌肉牵拉线的肌束方向和相对于肌肉长度的纤维长度

The difficulty of example 12 mainly lies in two long objects, literal translation of which like TT1 might result in a lengthy and jumbled Chinese sentence. Consequently, the translator decided to adopt the segmentation and amplification methods mentioned in 2.2. Firstly, the ST is thoroughly splited, and the category term "*决定因素*" was used to summarize the two coordinate components in ②. Then, the colon is employed to introduce these two objects. This allows Chinese readers to understand at a glance without the need for repeated scanning back and forth or analyzing complex sentence structures.

Example 13

ST: The muscle force was changed by varying both **the number of motor units that were active** and **the rate at which the motor neurons discharged action potentials**.

TT1: 肌力随着运动单位被激活的数量和运动神经元释放动作电位的速率变化而变化。

TT2: 运动单位被激活的数量和运动神经元释放动作电位时的速率，**这两种因素**不同，肌力也会不同。

Analysis:

In example 13, the difficulty lies in how to adjust the long sentence in TT1 into shorter ones that are more in line with the habits of Chinese expression. The parts "*the number of motor units that were active*" and "*the rate at which the motor neurons discharged action potentials*" were made into separate sentence and brought forward, summarized by the phrase "*这两个因素*". Consequently, the long sentence in TT1 was divided into three parts, making the logical relationship more explicit.

3.3 Strengthening Cohesion and Coherence in Discourse

A text is composed of words, sentences, or paragraphs, but it is not a mechanical accumulation of statements; rather, it is an organic and dynamic combination. Halliday and Hasan argue that in a text, certain words within a sentence have a continuous relationship with the context, or in other words, the specific meanings of certain words need to be indexed from the relevant words in the context. The former becomes the cohesive item, and the latter is the item being cohesive, with both forming a cohesive relationship. It is this cohesive relationship that makes the text a complete unity of form and meaning (Halliday, Hasan, 1976).

3.3.1 Integrating the Texts and Figures

A well-structured and logically coherent article is not just about the relationship between sentences, but also about the relevance between paragraphs (白丹妮, 2015: 6). As mentioned before, there is a large number of figures, which can explain and supplement the source sentences. Therefore, in order to maintain the overall coherence of the translation text, the translator has strengthened the connection between paragraphs and figures, and made appropriate adjustments to the original structure in conjunction with the illustrations.

Example 14

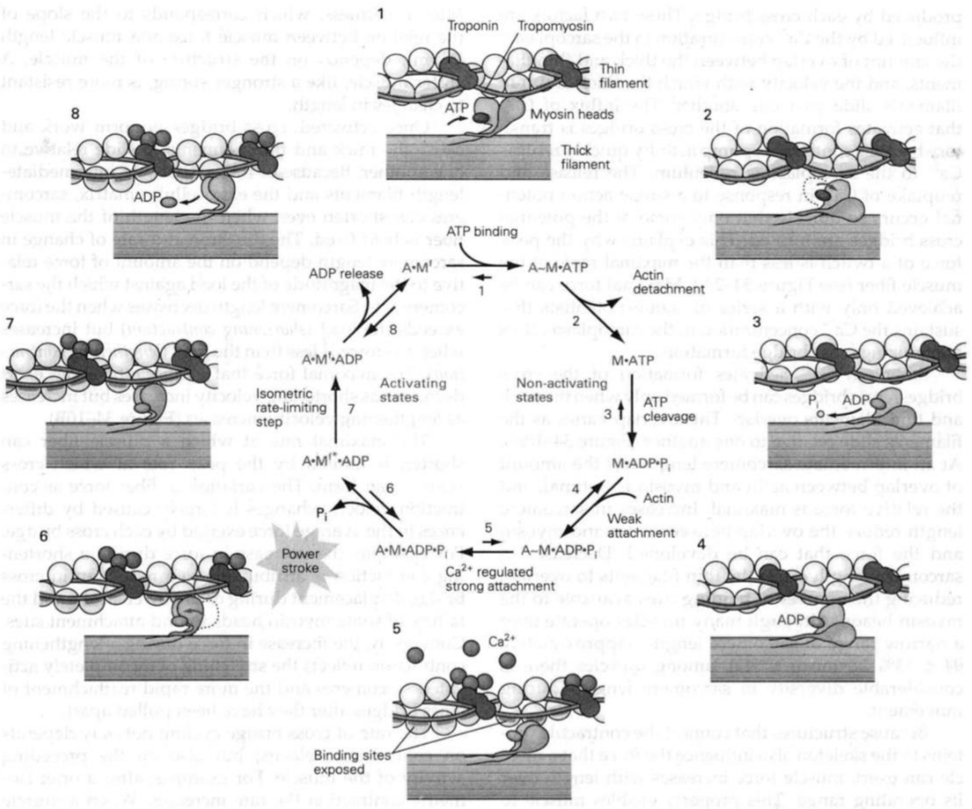

Figure 2

ST: The cycle begins at the top (**step 1**) with the binding of adenosine triphosphate (ATP) to the myosin head. The myosin head detaches from actin (**step 2**), ATP is hydrolyzed to phosphate (P_i) and ADP (**step 3**), and the myosin becomes weakly bound to actin (**step 4**). The binding of Ca^{2+} to troponin causes tropomyosin to slide over actin and enables the two myosin heads to close (**step 5**). This results in the release of P_i and <u>**the extension of the myosin neck**</u>, the power stroke of the cross bridge cycle (**step 6**). Each cross bridge exerts a force of about 2 pN during a structural change (**step 7**) and the release of adenosine diphosphate (ADP) (**step 8**). (•, strong binding; ~, weak binding; $\mathbf{M^f}$, cross bridge force of myosin; and $\mathbf{M^{f*}}$, force-bearing state of myosin.)

TT1: 周期从顶部开始，三磷酸腺苷（ATP）与肌球蛋白头结合（**第一步**）。肌球蛋白头与肌动蛋白分离（**第二步**）。ATP 水解为磷酸（P_i）和 ADP（**第三步**）。肌球蛋白与肌动蛋白弱结合（**第四步**）。Ca^{2+}与肌钙蛋白结合，导致原肌球蛋白在肌动蛋白上滑动，并使

两个肌球蛋白头闭合（**第五步**）。上一步导致 P_i 被解离，肌球蛋白颈**延伸**，即横桥周期的动力冲程（**第六步**）。上述构象改变期间，每个横桥施加大约 2pN 的力（**第七步**）。ADP 被解离（**第八步**）。（• ：强结合；~：弱结合；$\mathbf{M^f}$：肌球蛋白横桥力；$\mathbf{M^{f*}}$：肌球蛋白的受力状态。）

TT2: 横桥周期从图片顶部开始：

1.三磷酸腺苷（ATP）与肌球蛋白头结合。

2. 肌球蛋白头与肌动蛋白分离。

3. ATP 水解为磷酸（P_i）和 ADP。

4. 肌球蛋白与肌动蛋白弱结合。

5. Ca^{2+}与肌钙蛋白结合，导致原肌球蛋白在肌动蛋白上滑动，并使两个肌球蛋白头闭合。

6. 上一步导致 P_i 被解离，肌球蛋白颈向桥臂方向扭动，即横桥周期的动力冲程。

7. 上述构象改变期间，每个横桥施加大约 2pN 的力。

8. ADP 被解离。

（• ：强结合；~：弱结合；$\mathbf{M^f}$：肌球蛋白横桥力； $\mathbf{M^{f*}}$：肌球蛋白的受力状态。）

Analysis:

In example 14, each step of the cycle belongs to one paragraph, and "*(step)*" was added at the end of each sentence for division. **TT1** makes the paragraph too lengthy and complex, so the key focus is on how to simplify the structure of the paragraph and make the explanation of the *cross bridge cycle* clearer in the text, to facilitate readers in discovering the connection between the words and the pictures.

As illustrated in Figure 2, each stage of the cycle is denoted by a corresponding number from 1 to 8. To correspond each step with the image, the translator has adopted a segmented approach, dividing each step into a separate paragraph. This transforms the original long paragraph into several smaller ones, resulting in a clearer structure and facilitating easier association with the image.

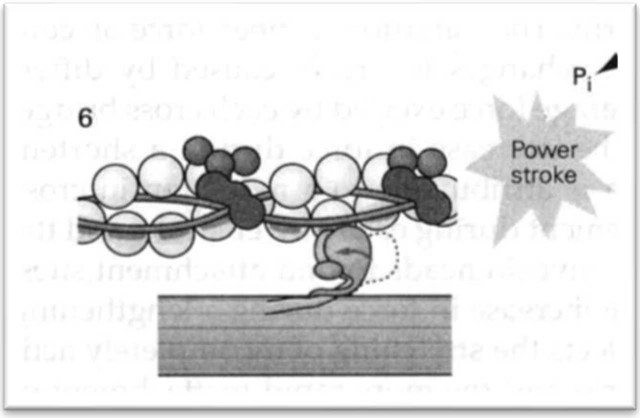

Figure 3

Additionally, the "*extension of the myosin neck*" also presents a challenge. In TT1, it was translated literally as "*肌球蛋白颈延伸*", but it not precise enough and could lead to misunderstandings. By observing the Figure 3 (the picture corresponding to this stage), we can see that the there is an arrow indicates the direction of movement of the myosin head. To better understand the specifics of this step, the translator consulted literature on the cross bridge cycle and discovered that this process is known as the "Ratchet Effect" — the myosin head twists 45° towards the bridge arm, thereby pulling the thin filaments towards the M line. Consequently, the translator, based on this explanation, specified "*extension 延伸*" as "*twist 扭动*", and the detail about the direction of twist was added to highlight the arrow in the Figure 3.

Example 15

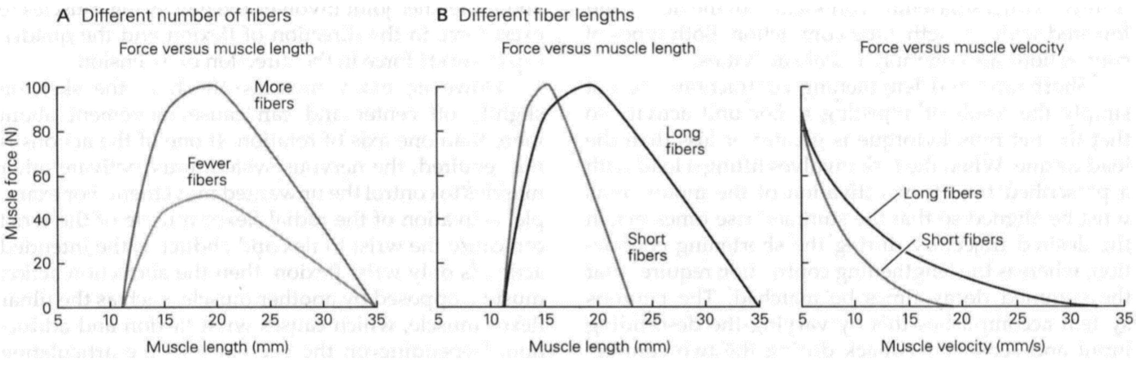

Figure 4

ST:

A. …… **<u>The muscle with twice as many fibers</u>** exerts greater force.

B. …… **<u>The muscle with longer fibers (about twice as long as those of the other muscle)</u>** has an increased range of motion (left plot). It also has a greater maximal shortening velocity and exerts greater force at a given absolute velocity (right plot).

TT1: ……**纤维数量为两倍的肌肉**会施加更大的力。……

TT2: ……**纤维数量更多的肌肉（是另一块肌肉的两倍）**会施加更大的力。……

Analysis:

In example 15, the main focus is on the expression of "*twice*". According to the captions in the Figure 4 and the following text, the sentence A. is rephrased to achieve structural equality. As illustrated in Figure 4, A. and B. form a control group, each exploring the impact of fiber number and fiber length on muscle force. Both expressing "*twice*", the original sentence in A. is "*with twice as many*…", while in B. employs a supplementary statement. Moreover，combining the descriptive text in the figure: "More fibers" & "Fewer fibers", "Long fibers" & "Short fibers", such an expression is more concise.

In order to achieve the structural equivalence and enhance the comparative effect in the translation, the translator adjusted and expanded the original sentence by imitating B. ——"*The muscle with more fibers (twice as many as those of the other muscle)*".

3.3.2 Merging or Segmenting for Clarity

In English, the boundaries of sentences are marked by complete grammatical structures, while in Chinese, they are determined by the complete meaning. When handling scientific English, especially when dealing with a group of sentences that revolve around the same topic, we can integrate some sentences as subordinate clauses or short sentences into others based on their logical relationships, achieving a downward transformation from sentence group to sentence. This makes the structure more compact and the information more centralized. The specific approach requires clarifying the relationships between sentences in the original text, establishing hierarchical meaning, and then appropriately merging two or more sentences when appropriate, or segmenting long sentences into several shorter ones.

Example16

ST: Because these contractile properties of a motor unit depend on the characteristics of its muscle fibers(S1), we can distinguish different types of muscle fibers(S2). **This distinction stems from** structural specializations and differences in the metabolic properties of muscle fibers(S3).

TT1: 这些运动单位的收缩特性取决于其肌肉纤维的特征，所以我们能够区分不同类型的肌肉纤维。**这种区分源于**肌肉纤维的结构特异性和不同的代谢特性。

TT2: 运动单位的收缩特性是由肌纤维的特性决定的，因此，我们可以**根据**运动单位的收缩特性，判断肌肉纤维的结构和代谢差异，区分肌肉纤维的不同类型。

Analysis:

The original text consists of three independent sentences revolving around the topic of distinguishing muscle fiber types. In translation, the principle “end where the meaning ends” can be used to merge sentences with related meanings into an information cluster discussing a single topic. Firstly, based on “*we can distinguish different types*” and “*This distinction stems from*”, the translator inferred that the criteria for distinguishing are “*structural specializations*” and “*differences in metabolic properties*”. Secondly, further clarified the causal relationship between S1 and S2. In the original text, S2 directly states the conclusion but does not explicitly explain what is used to distinguish different types of muscle fibers. In TT2, in order to make the sentence more coherent and logically clear, the translation adds “*我们可以根据运动单位的收缩特性*”, allowing the reader to clearly understand that the basis for distinguishing muscle fiber is the contraction characteristics of motor units. After clarifying the connections between the various bureaus, the translator combined the three independent sentences and embedded S3 as a subordinate clause within TT2, forming an information cluster that discusses the same topic.

Example 17

ST: Force is increased during a muscle contraction by the activation of additional motor units, which are recruited progressively from the weakest to the strongest. A motor unit’s recruitment threshold is the force during the contraction at which the motor unit is activated. Muscle force decreases gradually by terminating the activity of motor units in the **reverse** order from strongest to weakest.

TT1: 在肌肉收缩过程中，运动单位由弱到强逐一被激活，肌力不断变大。运动单位的招募阈值是指肌肉收缩过程中，激活运动单位所需的最小力量水平。按照**由弱到强的相反顺序**，运动单位的活性被逐一终止，肌力逐渐减小。

TT2: 在肌肉收缩过程中，运动神经元按照由弱到强的顺序逐一激活运动单位，肌力不断变大，激活运动单位所需的最小力量水平叫作运动单位的招募阈值。**与激活顺序相反**，运动单位由强到弱被终止活性，肌力逐渐减小。

Analysis:

The challenge in translating example 17 lies in eliminating ambiguity and clarifying the source message. The focus of the translation is on the phrase "*the reverse order from strongest to weakest*". TT1's direct translation, "*由弱到强的相反顺序*" was found to be ambiguous during the review with team members, leading to reader confusion—whether "*由弱到强的相反顺序*" means "*由强到弱*", which is completely opposite to the source text's intent. The specific meanings of certain words need to be indexed from the relevant words in the context. "*Reverse*" refers to the order of motor unit activation mentioned earlier，that is, "*recruited progressively from the weakest to the strongest*". To eliminate ambiguity and highlight the main theme of the source text一the size principle of motor neuron recruitment, the translator extracted "*reverse*" as an independent structure from the sentence, explicit the contrasting structure with the previous text. This method not only made the source text more coherent and smoother but also allowed readers to immediately understand the true meaning of the source text.

Chapter 4 Conclusion

During the translation practice, I fully recognized the critical role of proofreading in ensuring translation quality. To this end, I implemented a rigorous multi-stage proofreading process, encompassing self-proofreading, group review, and mentor oversight. Through these iterations, I carefully reviewed and refined the translation, gaining invaluable insights. In this chapter, I reflect on my experiences, identify areas for improvement, and lay the groundwork for future translations of even higher caliber.

4.1 Proofreading

Proofreading is not an independent process of translation, nor the final. It actually runs through the entire translation process. If the focus of proofreading is only placed at the end, hoping that the last process can completely solve all the problems accumulated in the early stage and achieve perfect work this is obviously impossible (岳峰, 2019: 94).

During this translation practice, the translator went through three stages: initial translation, proofreading, and re-proofreading. At the beginning, she promptly recorded the difficulties encountered, solutions, and analysis (Figure 5). During the proofreading process, she mainly focused on the difficulties and solutions in the previous stage, reflected on whether they were reasonable, and further considered better translation methods. When reviewing again, she read the translated text as an independent article, making sure the unity and coherence in writing and if there are any logical inconsistencies.

At the level of the muscle, the functional attributes of the fibers are modified by the orientation of the fascicles to the line of pull of the muscle and the length of the fiber relative to the muscle length.
两个宾语太长，如果直接翻译，句子过于臃肿。因此，分割原文的一长句，用范畴词“因素”概括两个长宾语，接着用冒号引出，添加序号可以使译文结构更加清晰。（原因）

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The muscle with longer fibers (about twice as long as those of the other muscle) has an increased range of motion (left plot). It also has a greater maximal shortening velocity and exerts greater force at a given absolute velocity (right plot).
1：纤维较长的肌肉（大约是另一块肌肉的两倍），其运动范围更大（左图），最快缩短速度更快，在给定的绝对速度下施加的力更大（右图）。
2：纤维较长的肌肉（大约是另一块肌肉的两倍），其运动范围（左图）、最快缩短速度以及在给定的绝对速度下施加的力（右图）都比另一块肌肉大。
分析：虽然是两句话，但主语相同，三小句都是两块肌肉的对比，而且结果都是相同的，翻译 1 有点啰嗦，所以用顿号把这三种比较连接，最后统一说结果。

Figure 5

Next is peer review among team members, with a focus on the readability (Figure 6). They marked translations that are lengthy or difficult to understand, and then refer to the original text to discuss improvement methods.

首先，目标在空间中相对于身体的某些部分，如头部或手臂（以自我为中心的空间）被定位。在这个过程中，有几个信息源被结合起来。例如，目标相对于头部的位置是根据目标在每个视网膜上的位置和眼睛的注视方向计算出来的（图33-2A）。一个人还需要知道他的手或他希望放在目标上的工具顶端的初始位置（终端效应器或端点）。端点的初始位置可以通过结合视觉输入、本体感觉信号和触觉来估计，每一种都可以提供位置信息。一旦计算出手臂的当前位置和目标的位置，就可以计划一个运动。一个运动计划通常既要指定一个特定的路径、终点的连续空间位置，也要计算一组可以到达终点的关节角度，这被称为逆运动学转换（图33-2C）。这种转换必须考虑到手臂的几何参数，如上臂和前臂的长度（回顾一下，运动学考虑的是运动而不是引起运动的力）。运动系统通过激活在关节处产生扭力（旋转力）的肌肉来控制关节角度。	相对于身体的某些部分，对目标的空间位置进行定位。这个过程结合了几种信息源。（空间定位目标——不确定有没有这种说法） 运动系统激活肌肉，在关节处产生扭力，控制关节角度。

Figure 6

At last, the mentor will conduct a review, paying attention to whether the original text is understood correctly, and providing revision suggestions for key and difficult issues.

4.2 Gains

In this translation practice, the translator faced a brand new and unknown field. Firstly, she realized the importance of “cross-discipline plus translation”. Translator focused more on basic language skills and have a single knowledge structure. In the future, she will pay attention to the deep integration of linguistic competence and professionalism, so as to reaching the level of “strong linguistic competence and high professionalism” (崔建强，季骄阳, 2021: 111).

Secondly, this practice also provided some inspiration for the translator’s career development. In today’s market, enterprises and institutions often require translators with in-depth industry knowledge to handle professional literature and communication needs more accurately and efficiently. By focusing on specialized knowledge in a specific field and combining it with excellent translation skills, translators have the opportunity to shape their unique competitiveness as a professional translator in that field.

Translation can never be perfect. It is an endless process, and problems can always be identified as long as they are viewed with a critical eye (李长栓, 2012: 379). By continuously comparing the original sentence, examining the translation, and absorbing feedback, translators can continuously improve the translation quality, making it more closely aligned with the original intention and the reading habits of the target readers. Therefore, translators should embrace a learning mindset and be open to constant refinement of their translations, striving for ever higher standards of quality.

4.3 Limitations

Due to insufficient understanding of certain professional terms and backgrounds, there are certain deficiencies in the translation. In future translation work, the translator needs to strengthen her learning and understanding of relevant field knowledge in order to more accurately and appropriately convey the meaning of the original text. At the same time, attention should also be paid to communication and cooperation with professionals, constantly improving one’s translation skills, in order to provide higher quality translation services.

In this translation practice, the translator found that there are certain limitations in her comprehensive language proficiency, which may result in translations that lack fluency, and logic and coherence need to be improved. To overcome this shortcoming, the translator plans to focus on enhancing her writing skills in future translation work, including learning from excellent writing techniques and styles, reading and writing more, and continuously refining her ability to express in writing.

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Appendix 1: Glossary

A		
1	achilles tendon	跟腱
2	actin	肌动蛋白
3	action potential	动作电位
4	activation Strategies	激活策略
5	active ROM	主动关节活动
6	adenosine diphosphate	腺苷二磷酸
7	adenosine triphosphate	腺苷三磷酸
8	adipose tissue	脂肪组织
9	ADP	腺苷二磷酸
10	angular acceleration	角加速度
11	angular displacement	角位移
12	angular momentum	角动量
13	angular motion	角[向]运动
14	angular velocity	角速度
15	areolar tissue	蜂窝组织
16	axis of rotation	旋转轴
17	axon	轴突
B		
18	basal lamina	基板
19	biceps brachii	肱二头肌
20	binding protein	结合蛋白质
21	binding site	结合位点
22	biogenesis	生物合成
23	body segment	人体环节
24	Brachioradialis	肱桡肌
25	brain stem	脑干
C		
26	calcium	钙
27	calcium pump	钙泵
28	capillary	毛细血管
29	cell bodies	细胞体
30	coiled coil	卷曲螺旋
31	coiled-coil domain	卷曲螺旋结构域
32	collateral sprout axon	侧支出芽轴突
33	connective tissue	结缔组织
34	contractile properties	收缩特性

35	contractile protein	收缩蛋白质
36	contraction speed	收缩速度
37	costamere	肋节
38	crania1 nerve	颅神经
39	Cricothyroid	环甲肌
40	cross bridge	横桥
41	cytoplasm	胞质
42	cytoskeleton	细胞骨架
D		
43	dark band	暗带
44	decerebrate	去脑，切除大脑 n.去（大）脑动物
45	deltoid	三角肌
46	dendrites	树突
47	dense connective tissue	致密结缔组织
48	depolarizes	去极化
49	descending input	下行输入
50	desmin	结蛋白
51	Discharge Rate	放电速率
52	discrete compartments	离散区室
53	dopamine	多巴胺
54	Dorsal interossei	骨间背侧肌
55	dystroglycan	肌养蛋白聚糖
56	dystrophin	肌养蛋白
E		
57	elbow	肘
58	electromyogram	肌电图
59	electromyogram signal	肌电信号
60	electromyographic recording	肌电数据
61	EMG	肌电图
62	EMG activity	肌电活动
63	EMG signal	肌电信号
64	Endurance exercise	耐力锻炼
65	enzyme	酶
66	enzyme activity	酶活力，酶活性
67	EPSP	兴奋性突触后电位
68	excitation-contraction coupling	兴奋-收缩耦合
69	excitatory inputs	兴奋性输入
70	excitatory post-synaptic potential	兴奋性突触后电位
71	excitatory synapse	兴奋性突触
72	excitatory synaptic current	兴奋性突触电流

73	extensor	伸肌
74	extracellular currents	胞外电流
75	extracellular matrix	细胞外基质
F		
76	F-actin	纤丝状肌动蛋白
77	fasciculus	神经束
78	fast-twitch	快收缩
79	fast-twitch and slow-twitch	快扭和慢扭
80	fatigability	疲劳性
81	fibronectin	纤连蛋白
82	fibrous actin	纤丝状肌动蛋白
83	field potential	场电位
84	firing rate	发放频率
85	first dorsal interosseous muscle	第一骨间背侧肌
86	flexion-extension	屈伸
87	flexor	屈肌
88	force capacity	承载力
G		
89	Gastrocnemius	腓肠肌
90	given volume	给定体积
91	glycoprotein	糖蛋白
92	groove	沟
H		
93	habitual levels of physical activity	习惯性体力活动水平
94	hamstring	绳肌腱
95	helical	螺旋的;螺旋形的
96	hip flexor	髋屈肌
I		
97	inertia	惯性
98	inertial mass	惯性质量
99	Innervation number	神经支配数
100	integrin	整联蛋白
101	integrin family	整合素家族
102	interneuron	中间神经元
103	intramuscular electrode	肌内电极
104	inward Ca^2 currents	内向钙电流
105	inward calcium current	内向钙电流
106	ion channel	离子通道
107	isometric contraction	等长收缩
108	isometric loading	等长负载
109	isotonic loading	等张力负载

	L	
110	laminin	层粘连蛋白
111	lengthening contraction	拉长收缩
112	light band	明带
113	limb immobilization	肢体制动
114	load torque	负荷力矩
115	longitudinal tubule	纵小管
116	L-type Ca^{2} channel	L 型钙通道
117	Lumbricales	蚓状肌
	M	
118	Masseter	咬肌
119	medial gastrocnemius	腓肠肌内侧头
120	medial gastrocnemius muscle	内侧腓肠肌
121	membrane potential	膜电位
122	membrane resistance	膜电阻
123	membrane-associated protein	膜结合蛋白
124	metabolic	代谢的，新陈代谢的
125	metabolic properties	代谢特性
126	mitochondria	线粒体(pl)
127	mitochondrion	线粒体
128	moment arm	矩臂
129	monoamine	一元胺
130	monoaminergic antagonist	单胺能拮抗剂
131	monoaminergic nerve	单胺能神经
132	Monoaminergic neurons	单胺能神经元
133	monoaminergic neurotransmitter	单胺能神经递质
134	monoaminergic pathway	单胺能通道
135	monoaminergic receptor	单胺类递质受体
136	monoaminergic system	单胺能系统
137	monoaminergic terminal	单胺能末梢
138	monoaminergic transmitter	单胺能递质
139	monoamines serotonin	单胺类血清素
140	motor neuron	运动神经元
141	motor neuron pool	运动神经元池
142	motor neuron pool	运动神经元池
143	motor neuron recruitment	运动神经元募集
144	motor nucleus	运动核
145	motor unit	运动单位
146	muscle contractions	肌肉收缩
147	muscle fascicle	肌束
148	Muscle Fiber	肌肉纤维

149	muscle fiber	肌肉纤维
150	muscle fiber membrane	肌纤维膜
151	muscle fibers	肌肉纤维
152	Muscle Force	肌力
153	Muscle stiffness	肌肉紧度
154	muscle stiffness	肌肉硬度
155	muscle synergy	肌肉协同模式
156	muscle torque	肌力矩
157	muscular dystrophy	肌营养不良
158	musculoskeletal geometry	肌肉骨骼几何
159	Mutation	突变
160	myofibril	肌原纤维
161	myosin	肌球蛋白
162	myosin adenosine triphosphatase	肌球蛋白腺苷三磷酸酶
163	myosin head	肌球蛋白头
164	myosin heavy chain	肌球蛋白重链
165	myosin heavy chain isoforms	肌球蛋白重链异构体
166	myosin molecule	肌球蛋白分子
	N	
167	nebulin	伴肌动蛋白
168	nerve bundle	神经束
169	net excitatory input	净兴奋性输入
170	neuromuscular synapse	神经肌肉突触
171	neurotransmitter	神经递质
172	noradrenaline	去甲肾上腺素
	O	
173	Ohm's law	欧姆定律
174	Opponens pollicis	拇对掌肌
175	optimal initial length	最适初长度
176	optimal preload	最适前负荷
	P	
177	patellar tendon	髌腱
178	peak force	峰值力
179	pennate muscle	羽状肌
180	pennation angle	羽状角
181	perimysium	肌束膜
182	peripheral nerve	末梢神经
183	persistent inward current	持续性内向电流
184	phosphate	磷酸
185	physical activity	体力活动
186	Platysma	颈阔肌

187	Plyometric contraction	超等长收缩
188	polypeptide chain	多肽链
189	positive work	正功
190	Posterior cricoarytenoid	环杓后肌
191	power stroke	动力冲程
192	progressive loading	递增负载
193	protein	蛋白质
Q		
194	quadriceps	股四头肌
R		
195	radial flexor muscle of the wrist	桡侧腕屈肌
196	rate of firing	发放频率
197	reaction force	反作用力
198	recruitment threshold	招募阈值
199	Rectus lateralis	外直肌
200	regulatory protein	调节蛋白
201	resting membrane potential	静息膜电位
202	ripple	纹波
S		
203	sarcolemma	肌膜
204	sarcomere	肌节
205	sarcoplasm	肌质
206	sarcoplasmic reticulum	肌质网
207	sartorius	缝匠肌
208	scapula	肩胛骨
209	self-sustained firing	自持续放电
210	serotonin	血清素
211	shortening contraction	缩短收缩
212	shortening velocity	缩短速度
213	sigmoidal function	Sigmoid 函数
214	size principle	大小原则
215	skelemin	骨架蛋白
216	skeletal muscle	骨骼肌
217	sliding filament hypothesis	肌丝滑行学说
218	slow-twitch	慢收缩
219	smooth endoplasmic reticulum	光面内质网
220	soleus	比目鱼肌
221	spina1 cord	脊髓
222	spinal	脊髓的;脊柱的;脊的
223	spinal cord	脊髓
224	strain energy	应变能

225	strength training	力量训练
226	strength-to-mass ratio	肌力与质量之比
227	stretch-shorten cycle	拉长—缩短周期
228	striated muscle	横纹肌
229	Structural element	结构元件
230	structural specializations	结构特异性
231	support phase	支撑期
232	swing phase	迈步期
233	synaptic current	突触电流
234	synaptic input	突触输入
	T	
235	talin	踝蛋白
236	target muscle	靶肌肉
237	Temporalis	颞肌
238	tendon	腱
239	Tensor tympani	鼓膜张肌
240	terminal cisterna	终池
241	tetanic contraction	强直收缩
242	tetanus	破伤风
243	the Contractile Proteins	收缩蛋白
244	the cross bridge cycle	横桥周期
245	the first dorsal interosseous muscle	第一骨间背侧肌
246	the line of pull	牵拉线
247	the median and ulnar nerves	正中神经和尺神经
248	the pool of motor neurons	运动神经元池
249	thick filament	粗肌丝
250	thigh	大腿
251	thin filament	细肌丝
252	Tibialis anterior	胫骨前肌
253	tibialis anterior muscle	胫骨前肌
254	titin	肌连蛋白
255	torque	扭矩
256	touchdown speed	接地速度
257	trajectory	轨迹
258	transfer protein	转运蛋白
259	transmembrane protein	穿膜蛋白
260	transmembrane resistance	穿膜电阻
261	Transverse arytenoid	杓横肌
262	transverse tubules	横小管
263	tropomyosin	原肌球蛋白
264	troponin	肌钙蛋白

265	twitch force	收缩力
266	two-joint	双关节
	U	
267	ulnar flexor muscle	尺屈肌
268	unmyelinated axon	无髓鞘轴突
	V	
269	ventral root	脊神经前根
270	ventral spinal cord	腹侧脊髓
271	vertebrate muscles	脊椎动物肌肉
272	vinculin	黏着斑蛋白
273	voltage clamp	电压钳
274	voluntary contraction	自愿性收缩
	W	
275	work capacity	作功能力
276	wrist adduction	腕内收
277	wrist joint	腕关节
	Z	
278	Z disk	Z 盘

Appendix 2: Source Text and Target Text

Source Text	Target Text
The Motor Unit and Muscle Action	**运动单位与肌肉动作**
The Motor Unit Is the Elementary Unit of Motor Control	**运动单位是肌肉控制的基本单位。**
A Motor Unit Consists of a Motor Neuron and Multiple Muscle Fibers	一个运动单位由一个运动神经元和多跟肌肉纤维组成。
The Properties of Motor Units Vary	运动单位的属性不同
Physical Activity Can Alter Motor Unit Properties	体力活动可以改变运动单位的属性
Muscle Force is Controlled by the Recruitment and Discharge Rate of Motor Units	运动单位的募集和放电速率决定肌力
The Input-output Properties of Motor Neurons are Modified by Input from the Bram Stem	脑干的输入改变运动神经元的输入-输出特性
Muscle Force Depends on the Structure of Muscle	**肌肉结构决定肌力**
The Sarcomere Contains the Contractile Proteins Noncontractile Elements Provide Essential Structural Support	肌节含有收缩蛋白非收缩元素提供必要的结构支撑
Contractile Force Depends on Muscle Fiber Activation, Length, and Velocity.	肌纤维激活、长度和速度决定收缩力
Muscle Torque Depends on Musculoskeletal Geometry	肌肉骨骼几何决定肌肉力矩
Different Movements Require Different Activation Strategies	**不同的运动需要不同的激活策略**
Contraction Velocity Can Vary in Magnitude and Direction	收缩大小和方向不同，收缩速度不同
Movements involve the Coordination of Many Muscles	运动涉及多种肌肉的协调合作
Muscle Work Depends on the Pattern of Activation	激活模式决定肌肉工作

An Overall View	**本章小节**
ANY ACTION——ASCENDING A FLIGHT of stairs, typing on a keyboard, even holding a pose——requires coordinating the movement of body parts. This is accomplished by the interaction of the nervous system with muscle. The role of the nervous system is to activate just those muscles that will exert the force needed to move in a particular way. This is not a simp1e task: Not only must the nervous system decide which muscles to activate and how much to activate them in order to move one part of the body, but it must a1so control muscle forces on other body parts and maintain posture.	任何动作——爬楼梯，敲键盘，甚至保持一个姿势不动——都需要协调身体各个部分的运动。这个过程中，神经系统和肌肉相互作用。神经系统的作用是激活肌肉，使之施加特定运动所需的力。这并不是一项简单的任务：为了移动身体的某一部分，神经系统需要决定激活哪些肌肉、激活多少肌肉，还必须控制身体其他部分的肌力并保持姿势。
This chapter examines how the nervous system contro1s muscle force and how the force exerted by a limb depends on muscle structure. We also describe how muscle activation differs with different types of movement.	本章节研究神经系统如何控制肌力，以及肌肉结构如何决定肢体施加力量。我们还描述了肌肉激活策略随运动类型的变化而改变。
The Motor Unit Is the Elementary Unit of motor Control	**运动单位是控制运动的基本单位。**
A Motor Unit Consists of a Motor Neuron and Multiple Muscle Fibers	**一个运动单位由一个运动神经元和多跟肌肉纤维组成。**
The nervous system controls muscle force with signals sent from motor neurons in the spinal cord to the muscle fibers. A motor neuron and the muscle fibers it innervates are known as a motor unit, the basic functiona1 unit by which the nervous system contro1s movement, a concept proposed by Char1es Sherrington in 1925.	神经系统从脊髓中的运动神经元发送信号至肌肉纤维，从而控制肌力。一个运动神经元和其所支配的肌肉纤维被称为一个运动单位。运动单位是神经系统控制运动的的基本功能单位，这一概念由查尔斯·谢灵顿（Charles Sherrington）于 1925 年首次提出。

A typical muscle is controlled by a few hundred motor neurons whose cell bodies are clustered in a motor nucleus in the spina1 cord or brain stem (Figure 34-1). The axon of each motor neuron exits the spina1 cord though the ventral root or through a crania1 nerve in the brain stem and runs in a peripheral nerve to the muscle. When the axon reaches the muscle, it branches and innervates from a few to several thousand muscle fibers.	一般的肌肉由几百个运动神经元控制，这些神经元的胞体聚集在脊髓或脑干的运动核中（图 34-1）。每个运动神经元的轴突通过脊神经前根或脑干中的颅神经穿过脊髓，接着通过末梢神经到达肌肉。到达肌肉时，轴突发出分支，支配几根到上千根肌肉纤维。
Figure 34-1 A typical muscle consists of many thousands of muscle fibers working in parallel and organized into a smaller number of motor units. A motor unit consists of a motor neuron and the muscle fibers that it innervates, illustrated here by motor neuron A1. The motor neurons innervating one muscle are usually clustered into an elongated motor nucleus that may extend over one to four segments within the ventral spinal cord. The axons from a motor nucleus exit the spinal cord in several ventral roots and peripheral nerves but are collected into one nerve bundle near the target muscle. In the figure, motor nucleus A includes all those motor neurons innervating muscle A; muscle B is innervated by motor neurons lying in motor nucleus B. The extensively branched dendrites of one motor neuron tend to intermingle with those of motor neurons from other nuclei.	**图 34-1** 一般的肌肉通常由成千上万的肌纤维组成，这些肌纤维同时工作，组成了数量较少的运动单位。一个运动单位由一个运动神经元和其所支配的肌纤维组成，这里用运动神经元 A1 来说明。支配某一肌肉的运动神经元通常聚集在一个细长的运动核中，该运动核可能在腹侧脊髓中延伸一到四个节段。在数个脊神经前根和末梢神经中，运动核的轴突穿出脊髓，在靶肌肉附近汇集成一个神经束。图中，运动核 A 包括所有支配肌肉 A 的运动神经元；运动核 B 中的运动神经元支配肌肉 B。

Once synaptic input depolarizes the membrane potential of a motor neuron above threshold, the neuron generates an action potential that is propagated along the axon to its terminal in the muscle. The action potential releases neurotransmitter at the neuromuscular synapse, and this cause an action potential in the sarcolemma of the muscle fibers. A muscle fiber has electrical properties similar to those of a large- diameter, unmyelinated axon, and thus action potentials propagate along the sarcolemma, although more slowly owning to the fiber's higher capacitance. Because the action potentials in all the muscle fibers of a motor unit occur at approximately the same time, they contribute to extracellular currents that sum to generate a field potential near the active muscle fibers.	一旦突触输入使运动神经元的膜电位去极化超过阈值，神经元就会产生一个动作电位，该动作电位沿着轴突传递到肌肉的末端。动作电位于神经肌肉突触释放神经递质，从而在肌纤维的肌膜中产生动作电位。肌纤维的电特性类似于大直径无髓鞘轴突，因此动作电位沿着肌膜传播，然而由于肌纤维的高电容属性，其传播速度较慢。运动单位的全部肌肉纤维中，动作电位几乎在同一时间产生，继而引起的胞外电流在活性肌纤维附近产生场电位。
Most muscle contractions involve the activation of many motor units, whose currents sum to produce signals detected by electromyography. In many instances the electromyogram (EMG) signal is large and can be easily recorded with electrodes placed on the skin over the muscle. The timing and amplitude of EMG activity, therefore, reflect the activation of muscle fibers by the motor neurons. EMG signals are useful for studying the neural control of movement and for diagnosing pathology (see Chapter 14).	大多数肌肉收缩需要激活许多运动单位，肌电图能够检测到所有这些单位电流产生的信号。大多数情况下，肌电信号很大，放置在肌肉皮肤上的电极可以轻易记录下来。因此，肌电活动的时间和振幅反映了运动神经元对肌肉纤维的激活情况。肌电信号可用于研究神经运动控制和诊断病症。（见第 14 章）

In most mature vertebrate muscles, each fiber is innervated by a single motor neuron. The number of muscle fibers innervated by one motor neuron, the innervation number, varies with the muscle type and function. In human skeletal muscles it ranges from average values of 5 for an eye muscle to 1,800 for a leg muscle (Table 34-1). Because the innervation number denotes the number of muscle fibers within a motor unit, differences in innervation number indicate differences in the average increment in force that occurs each time a motor unit in the same muscle is activated. Thus, the innervation number also indicates the fineness of control of the muscle; the smaller the innervation number, the finer the control achieved by varying the number of activated motor units.	大多数成熟脊椎动物肌肉中，每根纤维由一个运动神经元控制。一个运动神经元所支配的肌纤维数目，即神经支配数目，随着肌肉类型和功能的不同而不同。在人类骨骼肌中，其范围从眼肌的平均值 5 到腿肌的 1800 不等（表 34-1）。因为神经支配数目表示运动单位内的肌纤维数量，所以其差异表示每次激活同一肌肉中的运动单位时，平均力量增量的差异。因此，神经支配数也代表肌肉控制的精细度；神经支配数量越少，通过改变运动单位的激活数量实现的控制就越精细。
Table 34-1 Innervation Numbers in the Human Skeletal Muscles	**表 34-1** 人类骨骼肌的神经支配数
Not all motor units in a muscle have the same innervation number. Indeed, the differences can be substantial. For example, motor units of the first dorsal interosseous muscle of the hand have innervation numbers ranging from approximately 21 to 1,770. Consequently, the strongest motor unit in the hand's first dorsal interosseous muscle can exert about the same force as the average motor unit in the leg's medial gastrocnemius muscle.	同一肌肉中，并非所有的运动单位都有相同的神经支配数。实际上，他们之间的差异巨大。例如，手部的第一骨间背侧肌，其运动单位的神经支配数从大约 21 到 1770 不等。因此，手部第一骨间背侧肌中最强运动单位所能发挥的力量与腿部内侧腓肠肌的平均运动单位差不多。

The muscle fibers of a single motor unit are distributed throughout the muscle and intermingle with fibers innervated by other motor neurons. The muscle fibers of a single motor unit can occupy from 8% to as much as 75% of the volume in a limb muscle, with 2 to 5 muscle fibers per 100 belonging to the same motor unit. Therefore, the muscle fibers in a given volume of muscle belong to 20 to 50 different motor units. This distribution changes with age and with some neuromuscular disorders. For example, muscle fibers lose their innervation after the death of a motor neuron and can be reinnervated by collateral sprouts from neighboring axons.	单个运动单位的肌肉纤维分布在整个肌肉中，并与其他运动神经元支配的纤维交织在一起。单个运动单位的肌纤维可占四肢肌肉总量的 8%至 75%，每 100 个肌纤维中有 2 至 5 个属于同一运动单位。因此，给定体积的肌肉中，肌纤维属于 20 至 50 个不同的运动单位。随着年龄的增长和某些神经肌肉疾病的影响，这种分布也随之改变。例如，一个运动神经元死亡后，肌纤维失去其神经支配，邻近轴突的侧枝重新支配该肌纤维。
In some muscles the fibers of motor units are confined to discrete compartments that correspond to the regions of the muscle supplied by the primary branches of the muscle nerve. Selective activation of different compartments that exert forces in different directions provides a biomechanical advantage. Branches of the median and ulnar nerves in the forearm, for example, innervate distinct compartments in three multitendon extrinsic hand muscles that enable the fingers to be moved relatively independently. A muscle can therefore consist of several functionally distinct regions.	某些肌肉中，运动单位的纤维被限制于离散区室内，这些离散区室与肌肉神经主要分支所支配的肌肉区域相对应。选择性激活不同施力方向的区室具有生物力学优势，例如，前臂正中神经和尺神经分支支配着三条多肌腱手外肌的不同区室，这样手指才能相对独立地移动。因此，一块肌肉可以由几个功能不同的区域组成。
The Properties of Motor Units Vary	**运动单位的属性不同**

The force exerted by a muscle depends not only on the number of motor units that are activated during a contraction but also on three properties of those motor units: contraction speed, maximal force, and fatigability. These properties are assessed by examining the force exerted by individual motor units in response to variations in the number and rate of evoked action potentials.	肌肉施加的力不仅取决于收缩时运动单位激活的数量，还取决于这些运动单位的三种属性：收缩速度，最大力量和易疲劳性。由于诱发动作电位的数量和频率发生变化，单个运动单位才施加一定的力，通过检验这种力，评估该运动单位属性。
The response to a single action potential is known as a *twitch contraction*. The time it takes the twitch to reach its peak force, the *contraction time*, is one measure of the contraction speed of the muscle fibers that comprise a motor unit. Slow-twitch motor units have long contraction times; fast-twitch units have shorter contraction times. A rapid series of action potentials elicits superimposed twitches known as a *tetanic contraction or tetanus*.	对单个动作电位的反应称作*单收缩*。收缩达到峰值力所需的时间，即*收缩时间*，是衡量构成运动单位的肌纤维收缩速度的标准。慢收缩运动单位的收缩时间长，快收缩单位的收缩时间短。一系列快速的动作电位引起的叠加收缩被称为*强直性收缩*或*强直收缩*。
Figure 34-2 The force exerted by a motor unit varies with the rate of the action potentials.	**图 34-2** 运动单位施加的力随动作电位的速率而变化。
A. Traces show the forces exerted by fast- and slow-twitch motor units in response to a single action potential (top trace) and a series of action potentials (set of four traces below). The time to the peak twitch force, or contraction time, is briefer in the fast-twitch unit.	**A.** 迹线显示，快收缩和慢收缩运动单位分别对单个动作电位（上方两条迹线）和一系列动作电位（下方四条迹线）做出反应，从而施加的力。快收缩运动单位，其收缩达到峰值力所需的时间（收缩时间）更短。

The rates of the action potentials used to evoke the tetanic contractions ranged from 17 to 100 Hz in the slow-twitch unit to 46 to 100 Hz in the fast-twitch unit. The peak force for the 100 Hz tetanus is greater in the fast-twitch unit. Note the different force scales for the two sets of traces. (Adapted with permission from Botterman et al. 1986; Fuglevand, Macefield, and Bigland-Ritchie 1999; and Macefield, Fuglevand, and Bigland-Ritchie 1996.)	在慢收缩运动单位中，能引起强直收缩的动作电位频率为 17~100Hz；在快收缩运动单位中，频率为 46~100Hz。100Hz 强直收缩的峰值力在快收缩单位中更大。请注意两组迹线的刻度不同。（经许可，改编自 1986 年 Botterman 等人；1999 年 Fuglevand, Macefield 和 Bigland-Ritchie； 1996 年 Macefield, Fuglevand 和 Bigland-Ritchie）
B. Relation between peak force and the rate of action potentials for fast- and slow-twitch motor units. The absolute force (left plot) is greater for the fast-twitch motor unit at all frequencies. At lower stimulus rates (right plot) the force evoked in the slow-twitch motor unit summed to a greater relative force (longer contraction time) than in the fast-twitch motor unit (briefer contraction time).	**B.** 快收缩和慢收缩运动单元的峰值力与动作电位频率之间的关系。快收缩运动单位在所有频率下的绝对力（左图）均较大。在较低的刺激频率（右图）下，慢收缩运动单位诱发的力的总和（收缩时间较长）比快收缩运动单位的（收缩时间更短）更大。
The force exerted during a tetanic contraction depends on the extent to which the twitches overlap and summate. The force varies with the contraction time of the motor unit and the rate at which the action potentials are evoked. At lower rates of stimulation the ripples in the tetanus denote the peaks of individual twitches (Figure 34-2A).	收缩重叠和相加的程度决定强直收缩施加的力。这种力随着运动单位的收缩时间和动作电位的诱发速度而变化。在较低的刺激频率下，强直收缩的曲线表示单收缩的峰值（图 34-2A）。

The peak force achieved during a tetanus varies as a sigmoidal function of action potential rate, with the shape of the curve depending on the contraction time of the motor unit (Figure 34-2B). Maximal force is reached at different action potential rates for fast-twitch and slow-twitch motor units and is often greater in fast-twitch units.	运动单位强直性收缩时力的峰值随动作电位频率的 Sigmoid 函数而变化，运动单位的收缩时间决定曲线的形状（图 34-2B）。快缩型和慢缩型运动单位在不同的动作电位频率下达到最大力，快缩型单位的力往往更大。
The functional properties of motor units vary across the population and between muscles. At one end of the distribution motor units have long twitch contraction times and produce small forces, but are difficult to fatigue. These motor units are the first activated during a voluntary contraction. In contrast, the last motor units activated have short contraction times, produce large forces, and are easy to fatigue. As observed by Jacques Duchateau and colleagues, most human motor units produce low forces and have intermediate contraction times (Figure 34-3).	不同人群或不同肌肉，其运动单位的功能属性不同。在某一收缩过程中，运动单位具有较长的单收缩时间，虽然产生的力较小，但不易疲劳。这些运动单位在自愿性收缩时首先被激活。后激活的运动单位，其收缩时间较短，产生的力量较大，但是易疲劳。Jacques Duchateau 及其同事发现，大多数人类运动单位产生的力量很小，收缩时间中等（图 34-3）。
Figure 34-3 Distributions of motor unit properties. (Reproduced, with permission, from Van Cutsem et al. 1997.)	**图 34-3** 运动单位属性的分布 （经许可，转载自 1997 年 Van Cutsem 等人）
A. Distribution of twitch torques for 528 motor units in the tibialis anterior muscle. **B.** Distribution of twitch contraction times for 528 motor units in the tibialis anterior muscle.	**A.** 胫骨前肌中，528 个运动单位抽搐扭矩的分布。 **B.** 胫骨前肌中，528 个运动单位抽动收缩时间的分布。
Because these contractile properties of a motor unit depend on the characteristics of its muscle fibers, we can distinguish different types of muscle fibers. This distinction stems from structural specializations	运动单位的收缩特性是由肌纤维的特性决定的，因此，我们可以根据运动单位的收缩特性，判断肌肉纤维的结构和代谢差异，区分肌肉纤维的不同类型。一个

<u>and differences in the metabolic properties of muscle fibers.</u> All muscle fibers belonging to a motor unit have similar biochemical and histochemical properties.	运动单位的所有肌肉纤维都具有类似的生物化学和组织化学特性。
One commonly used scheme distinguishes muscle fibers by their reactivity to histochemical assays for the enzyme myosin adenosine triphosphatase (ATPase), which is used as an index of contractile speed. Based on histochemical stains for myosin ATPase, it is possible to identify type I and type II muscle fibers. Slow contracting motor units contain type I muscle fibers, and fast contracting units include type II fibers. The type II fibers can be further classified into the least fatigable (type IIa) and most fatigable (type IIb, IIx, or IId). Another commonly used scheme distinguishes muscle fibers on the basis of genetically defined isoforms of the myosin heavy chain. Those in slow contracting motor units express myosin heavy chain-I, those in fast contracting and least fatigable units express myosin heavy chain-IIa, and fibers in fast contracting and most fatigable units express myosin heavy chain-IIb or -IIx. There is a high degree of correspondence between the two classification schemes for muscle fibers.	区分肌纤维最常用的方法是肌球蛋白腺苷三磷酸酶（ATPase）组织化学分析，通过肌纤维对该分析的反应可以划分不同类型，这一方法也被用作收缩速度指标。基于肌球蛋白 ATPase 的组织化学染色，可以识别 I 型和 II 型肌纤维。I 型肌纤维属于缓慢收缩性运动单位，II 型肌纤维属于快速收缩型运动单位。II 型肌纤维可以进一步划分为不易疲劳型（IIa 型）和易疲劳型（IIb，IIx，或 IId）。另一种常见方法是根据基因定义的肌球蛋白重链异构体区分肌纤维。缓慢收缩运动单位中，肌纤维的肌球蛋白重链表现为 I 型；快速收缩不易疲劳单位中为 IIa 型；快收缩易疲劳单位中为 IIb 或 IIx 型。这两种肌纤维分类方法高度契合。
Physical Activity Can Alter Motor Unit Properties	**体力活动可以改变运动单位的属性**
Alterations in habitual levels of physical activity can influence the three contractile properties of motor units (contraction speed, maximal force, and	习惯性体力活动水平发生变化会影响运动单位的三种收缩特性（收缩速度，最大力和疲劳性）。年龄增长、卧床休

fatigability). A decrease in muscle activity, such as occurs with aging, bed rest, limb immobilization, or space flight, reduces the maximal capabilities of all three properties. The effects of increased physical activity depend on the intensity and duration of the activity. Brief sets of high-intensity contractions performed a few times each week can increase contraction speed and motor unit force, whereas prolonged periods of low-intensity contractions can reduce motor unit fatigability. Physical activity regimens that involve such differences are often described as strength training and endurance training, respectively.	息、肢体制动或太空飞行等因素会减少肌肉活动，这会降低三种收缩特性的最大水平。能否增强体力活动取决于活动的强度和持续时间。每周进行几次短暂的高强度活动可以提高收缩速度和运动单位力量，长时间的低强度活动可以降低运动单位的疲劳性。这两种不同的体力活动方案通常被称作力量训练和耐力训练。
Changes in the contractile properties of motor units involve adaptations in the structural specializations and biochemical properties of muscle fibers. The improvement in contraction speed caused by strength training, for example, is associated with an increase in the maximal shortening velocity of a muscle fiber caused by the enhanced capabilities of the myosin molecules in the fiber. Similarly, the increase in maximal force is associated with the enlarged size and increased intrinsic force capacity of the muscle fibers produced by an increase in the number and density of the contractile proteins.	肌纤维结构特异性和生化特性的调整导致运动单位的收缩特性发生变化。例如，通过力量训练，纤维中肌球蛋白分子能力增强，加快了肌纤维最快缩短速度，从而加快了收缩速度。同样的，收缩蛋白的数量和密度增加，肌纤维就会变大，其内在动力增强，那么，最大力也会增加。
In contrast, alterations in the fatigability of a muscle fiber can be caused by many different adaptations, such as changes in capillary density, the number of mitochondria, excitation-contraction	相反，毛细血管的密度、线粒体数量、兴奋—收缩耦合或肌纤维代谢能力等发生变化，可能导致肌纤维疲劳性发生改变。耐力锻炼可以促进线粒体的生

coupling, and the metabolic capabilities of the muscle fibers. Endurance exercise can promote the biogenesis of mitochondria and enhance the oxidative capacity of a muscle fiber, thereby reducing its fatigability. Although the adaptive capabilities of muscle fibers decline with age, the muscles remain responsive to exercise even at 90 years of age.	物合成，增强肌纤维的氧化能力，从而降低疲劳性。虽然肌纤维的适应能力随着年龄的增长而下降，但人即使到了 90 岁，肌肉仍然对运动有反应。
Despite the efficacy of strength and endurance training in altering the contractile properties of muscle fibers, these training regimens have little effect on the composition of a muscle's fibers. Although several weeks of exercise can change the proportion of type IIa and IIx fibers, there is no change in the proportion of type I fibers. All fiber types adapt in response to exercise, although to varying extents depending on the type of exercise. For example, strength training of leg muscles for 2 to 3 months can increase the cross-sectional area of type I fibers by 0% to 20% and of type II fibers by 20% to 60%, increase the proportion of type IIa fibers by approximately 10%, and decrease the proportion of type IIx fibers by a similar amount. Furthermore, endurance training may increase the enzyme activities of oxidative metabolic pathways without noticeable changes in the proportions of fiber types, but the relative proportions of type IIa and IIx fibers do change as a function of the duration of each exercise session. Conversely, several weeks of bed rest or limb immobilization do not change the	力量和耐力训练可以有效改变肌纤维的收缩特性，但这些训练方案对肌纤维的构成几乎没有影响。几周的锻炼可以改变 IIa 型和 IIx 型纤维的比例，但是 I 型纤维比例毫无变化。所有类型的纤维在锻炼后都会适应性改变，改变的程度因运动类型而异。例如，对腿部肌肉进行 2 到 3 个月的力量训练可以使 I 型纤维的横截面积增加 0%至 20%，II 型纤维的横截面积增加 20%至 60%，IIa 型纤维比例增加约 10%，IIx 型纤维比例降低约 10%。此外，耐力训练可能会增加氧化代谢途径的酶活性，但不会明显改变纤维比例。然而，IIa 型和 IIx 型纤维的相对比例一定会随着每次锻炼的持续时间而变化。相反，几周的卧床休息或肢体固定并不会改变肌肉中纤维的比例，但一定会导致肌肉纤维的大小和内在力量减少。

proportions of fiber types in a muscle, but they do decrease the size and intrinsic force capacity of muscle fibers.	
Although physical activity has little influence on the proportion of type I fibers in a muscle, more substantial interventions can have an effect. Space flight, for example, exposes muscles to a sustained decrease in gravity reducing the proportion of type I fibers in leg muscles. A few weeks of continuous electrical stimulation at a low frequency causes a marked increase in the proportion of type I fibers and a substantial decrease in fiber size. Similarly, surgically changing the nerve that innervates a muscle alters the pattern of activation; eventually the muscle exhibits properties similar to those of the muscle that was originally innervated by the transplanted nerve. Connecting a nerve that originally innervated a rapidly contracting leg muscle to a slowly contracting leg muscle, for example, will cause the slower muscle to become more like a faster muscle.	尽管体力活动对肌肉中 I 型纤维的比例影响很小，但其他实质性的干预措施可以产生一定的影响。例如，太空飞行时，重力持续下降，在这种环境下，腿部肌肉中 I 型纤维的比例减少。连续进行几周的低频率电刺激会使 I 型纤维的比例明显增加，纤维体积大幅减少。同样，通过手术改变支配肌肉的神经后，激活模式也发生了变化。最终，肌肉表现出来的属性会类似于移植的神经原先所支配的肌肉的属性。例如，一个支配快收缩腿部肌肉的神经，若将其连接到慢收缩的腿部肌肉上，慢收缩的肌肉会表现得越来越像快收缩的肌肉。
Muscle Force Is Controlled by the Recruitment and Discharge Rate of Motor Units	**运动单位的募集和放电速率决定肌力**
The force exerted by a muscle during a contraction depends on the number of motor units that are activated and the rate at which each of the active motor neurons discharges action potentials. <u>Force is increased during a muscle contraction by the activation of additional motor units, which are</u>	收缩时的肌力取决于运动单位被激活的数量和活跃的运动神经元释放动作电位的速率。<u>在肌肉收缩过程中，运动神经元按照由弱到强的顺序逐一激活运动单位，肌力不断变大（图 34-4），激活运动单位所需的最小力量水平叫作运动单</u>

recruited progressively from the weakest to the strongest (Figure 34-4). A motor unit's recruitment threshold is the force during the contraction at which the motor unit is activated. Muscle force decreases gradually by terminating the activity of motor units in the reverse order from strongest to weakest.	位的招募阈值。与激活顺序相反，运动单位由强到弱被终止活性，肌力逐渐减小。
Figure 34-4 Motor units that exert low forces are recruited before those that exert greater forces (Adapted with permission, from Desmedt and Godaux 1977 and from Milner-Brown, Steinand Yemm1973.)	**图 34-4** 先招募力较小的运动单位，再招募力较大的运动单位。（经许可，改编自 1977 年 Desmedt 和 Godaux ，以及 1973 年 Milner Brown、Stein 和 Yemm）
A. Action potentials in two motor units were recorded concurrently with a single intramuscular electrode while the subject gradually increased muscle force. Motor unit 1 began discharging action potentials near the beginning of the voluntary contraction, and its discharge rate increased during the contraction. Motor unit 2 began discharging action potentials near the end of the contraction.	**A.** 当受试者逐渐增加肌肉力量时，同时记录两个运动单位的动作电位和一个肌内电极。运动单位 1 在自愿性收缩开始时释放动作电位，其放电速率在收缩过程中增加。运动单位 2 在在收缩快结束时释放动作电位。
B. Average twitch forces for motor units1 and 2 as extracted with an averaging procedure during the voluntary contraction.	**B.** 在自愿性收缩过程中，利用平均化过程设法得到运动单位 1 和 2 的平均收缩力。
C. The plot shows the forces at which 64 motor units in a hand muscle of one person were recruited (recruitment threshold) during a voluntary contraction versus the twitch forces of the motor units.	**C.** 该图显示，一个人的手部肌肉中，64 个运动单位在自愿收缩期间被募集使产生的力（招募阈值）对比运动单位的收缩力。
The order in which motor units are recruited is highly correlated with several indices of motor unit	运动单位被招募的顺序与运动单位大小指数高度相关，包括运动神经元细

size, including the size of the motor neuron cell bodies, the diameter and conduction velocity of the axons, and the amount of force that the muscle fibers can exert. Because the recruitment threshold of a motor unit depends on the membrane resistance of the motor neuron, which is inversely related to its surface area, a given synaptic current will produce larger changes in the membrane potential of small-diameter motor neurons. Consequently, increases in the net excitatory input to a motor nucleus cause the levels of depolarization to reach threshold in an ascending order of motor neuron size: The smallest motor neuron is recruited first and the largest motor neuron last (Figure 34-5). This effect is known as the size principle of motor neuron recruitment, a principle enunciated by Elwood Henneman in I957.	胞体的大小、轴突的直径和传导速度，以及肌肉纤维所能施加的力量大小。运动神经元膜电阻决定运动单位的招募阈值，而膜电阻与其表面积成反比，一定的突触电流会使小直径的运动神经元膜电位产生较大的变化。因此，运动核净兴奋性输入增加，去极化按运动神经元从小到大的顺序达到阈值：最小运动单位最先被募集，最大运动单位最后被募集（图 34-5）。这一效应被称作运动神经元募集的大小原则，于 1957 年 Elwood Henneman 提出。
Figure 34-5 The response of a motor neuron to synaptic input depends on its size.	**图 34-5** 运动神经元对突触输入的反应取决于其大小。
Two motor neurons of different sizes have the same resting membrane potential (V_r) and receive the same excitatory synaptic current (I_{syn}) from a spinal interneuron. Because the small motor neuron has a smaller surface area, it has fewer parallel ion channels and therefore a higher resistance (R_{high}). According to Ohm's law ($V = IR$), I_{syn} in the small neuron produces a large excitatory post-synaptic potential (EPSP) that reaches threshold, resulting in the discharge of an action potential. The small motor neuron has a small-diameter axon that conducts the	两个不同大小的运动神经元具有相同的静息膜电位（V_r），并从脊髓中间神经元接收相同的兴奋性突触电流（I_{syn}）。由于小型运动神经元的表面积较小，因此平行离子通道较少，因此电阻（(R_{high}）较高。根据欧姆定律（$V=IR$），小神经元中的 I_{syn} 产生一个大的兴奋性突触后电位（EPSP），此电位达到阈值，导致产生动作电位。小运动神经元的轴突直径小，以较低的速度（V_{siow}）将动作电位传导给较少的肌肉纤维。相反，大运动神

action potential at a low velocity (V_{slow}) to fewer muscle fibers. In contrast, the large motor neuron has a larger surface area, which results in a lower transmembrane resistance (R_{low}) and a smaller EPSP that does not reach threshold in response to I_{syn}.	经元表面积更大，这会导致穿膜电阻（R_{low}）较低，EPSP 较小，未达到能回应 I_{syn} 的阈值。
The size principle has two important consequences for the control of movement by the nervous system. First, the sequence of motor-neuron recruitment is determined by spinal mechanisms and not by higher regions of the nervous system. This means that the brain cannot selectively activate specific motor units. Second, motor units are activated in order of increasing fatigability, so the least fatigable motor units available produce the initial force required for a specific task.	大小原则对神经系统控制运动有两个重要的影响。首先，运动神经元的募集顺序由脊髓机制决定，而不是神经系统高级区域。这意味着大脑不能选择性地激活特定运动单位。其次，运动神经元按照疲劳程度递增的顺序，激活运动单位。因此，最不易疲劳型运动单位可以产生特定任务所需要的初始力。
As suggested by Edgar Adrian in the 1920s, the muscle force at which the last motor unit in a motor nucleus is recruited varies between muscles. In some hand muscles all the motor units have been recruited when the force reaches approximately 60% of maximum during a slow muscle contraction. In the biceps brachii, deltoid, and tibialis anterior muscles, recruitment continues up to approximately 85% of the maximal force. However, because the recruitment threshold of motor units decreases with contraction speed, during a rapid contraction most motor units in a muscle are recruited with a load of approximately 33% of maximum. Beyond the upper limit of motor unit recruitment, muscle force can still be increased	20 世纪 90 年代，Edgar Adrian 提出，在不同的肌肉中，运动核内最后一个运动单位募集的肌力是不同的。在一些手部肌肉的慢收缩过程中，当力达到峰值的 60%时，所有运动单位都被募集了。在肱二头肌、三角肌和胫骨前肌中，则需要达到峰值的 85%。然而，运动单位的招募阈值随着收缩速度降低而降低。因此，在快速收缩过程中，募集肌肉中的大多数运动单位只需要达到峰值的 33%。如果超过运动单位募集上限，通过改变运动神经元动作电位的速率，仍然可以增加肌力。募集上限以内，除了增加活跃的运动单位，还可以

by varying the rate of action potentials in the motor neurons. Below the upper limit of recruitment, the rate of firing can also be varied in addition to increasing the number of active motor units (Figure 34-6). In fact, beneath the upper recruitment limit variation in discharge rate can have the greater influence on muscle force.	改变发放频率。（图 34-6）。事实上，募集上限以内，放电速率的变化对肌力的影响更大。
Figure 34-6 Muscle force can be adjusted by varying the number of active motor units and their discharge rate.	**图 34-6** 通过改变活跃运动单位的数量及其放电速率，可以调节肌力。
A gradual increase and then a decrease in the force (blue line) exerted by the knee extensor muscles involved the concurrent activation of four (out of many) motor units. The muscle force was changed by varying both the number of motor units that were active and the rate at which the motor neurons discharged action potentials. Motor unit 1 was activated when muscle force reached 20% of maximum. Initially the motor neuron discharged action potentials at a rate of 9 Hz. As force increased, the discharge rate increased up to 15 Hz, when both the force and discharge rate declined, and the motor unit was inactivated at 14% of maximal force. Motor units 2, 3, and 4 were activated at greater forces but discharge rate was modulated similarly. (Reproduced, with permission, from Person and Kudina 1972.)	同时激活四个（多个）运动单元，膝伸肌施加的力（蓝线）逐渐增加，然后减少。运动单位被激活的数量和运动神经元释放动作电位的速率，这两种因素不同，肌力也会不同。肌力达到峰值的 20%时，运动单位 1 被激活。最初，运动神经元以 9Hz 的速率释放动作电位。当力和放电速率都下降时，随着力的增加，放电速率增加到 15Hz，并且运动单位在最大力的 14%时失活。运动单位 2、3、4 在力更大时被激活，但放电速率也受到类似的调制。（经许可，转载自 1972 年 Person 和 Kudina）
The Input-Output Properties of Motor Neurons Are Modified by Input from the Brain Stem	**脑干的输入改变运动神经元的输入—输出特性**

The discharge rate of motor neurons depends on the magnitude of the depolarization generated by excitatory inputs and the intrinsic membrane properties of the motor neurons in the spinal cord. These properties can be profoundly modified by input from monoam-inergic neurons in the brain stem. In the absence of this input, the dendrites of motor neurons passively transmit synaptic current to the cell body, resulting in a modest depolarization that immediately ceases when the input stops. Under these conditions the relation between input current and discharge rate is linear over a wide range.	运动神经元的放电速率取决于兴奋性输入产生的去极化大小和脊髓中运动神经元的内在膜性能。这些特性深受脑干中单胺能神经元输入的影响。如果没有此输入，运动神经元的树突被动地将突触电流传输给细胞体，导致一定程度的去极化，输入停止，去极化随即停止。在这些条件下，输入电流和放电速率之间在很大程度上是线性关系。
The input-output relation becomes nonlinear, however, when the monoamines serotonin and norepinephrine activate L-type Ca^{2+} channels on the dendrites of the motor neurons. The resulting inward Ca^{2+} currents can enhance synaptic currents by five- to tenfold (Figure 34-7). In an active motor neuron this enhanced current can sustain an elevated discharge rate after a brief depolarizing input, a behavior known as *self-sustained firing*. A subsequent brief inhibitory input at a low velocity returns the discharge rate to its original value.	然而，如果单胺类血清素和去甲肾上腺素激活了运动神经元树突的 L 型钙通道，那么这一关系就是非线性的。由此产生的内向钙电流可使突触电流增强 5~10 倍（图 34-7）。在活跃的运动神经元中，这种增强的电流可以在短暂的去极化输入后维持较高的放电率，即*自持续放电*。随后，在短暂低速的抑制性输入下，放电率恢复到初始值。
Figure 34-7 Effects of monoaminergic input on motor neurons. (Data from C. J. Heckman.)	**图 34-7** 单胺能输入对运动神经元的影响。（数据来源于 C. J. Heckman。）

A. Membrane currents and potentials in spinal motor neurons of adult cats that were either deeply anesthetized (low monoaminergic drive) or decerebrate (moderate monoaminergic drive). When monoaminergic input is absent or low, a brief excitatory input produces an equally brief synaptic current during voltage clamp (**upper record**). This current is not sufficient to bring the membrane potential of the cell to threshold for discharging action potentials (**lower record**). During high levels of monoaminergic input the same brief excitatory input activates a persistent inward current in the dendrites, which amplifies the synaptic current and generates a long-lasting tail current (**upper record**). This persistent inward current causes a high discharge rate during the input and the tail current sustains the discharge after the input ceases (**lower record**). A brief inhibition will return the cell to the resting state.	**A.** 深度麻醉（低单胺能驱动）或去脑（中等单胺能驱动）的成年猫，其脊髓运动神经元的膜电流和膜电位。当单胺能输入缺失或较低时，短暂的兴奋性输入在电压钳期间产生同样短暂的突触电流（**上方的记录**）。该电流不足以使细胞的膜电位达到释放动作电位的阈值（**下方的记录**）。在高水平的单胺能输入期间，相同的短暂兴奋性输入激活了树突中持续的内向电流，从而放大突触电流并产生持久的尾电流（**上方的记录**）。这种持续的向内电流在输入期间引起高放电率，并且尾电流在输入停止后维持放电（**下方的记录**）。短暂的抑制会使细胞恢复到静止状态。
B. With high levels of monoaminergic input the persistent inward current produces a much higher discharge rate for a given amount of current.	**B.** 在高水平的单胺能输入下，持续的内向电流对给定的电流产生更高的放电率。
C. When the entire motor pool innervating a muscle is considered, the monoamine-induced increase in the rate of motor neuron discharge produces a much larger force for a given amount of input and maximal force is achieved with less input to the motor neuron pool.	**C.** 当考虑支配肌肉的整个运动神经元池时，对于给定的输入量，单胺引起的运动神经元放电率的增加产生了更大的力，并且在运动神经元池输入较少的情况下获得了最大的力。

Because the properties of motor neurons are strongly influenced by monoamines, the excitability of the pool of motor neurons innervating a single muscle is under control of the brain stem. Moderate monoaminergic input to the motor neurons of slow contracting motor units promotes self-sustained firing. This is probably the source of the sustained force exerted by slower motor units to maintain posture. During sleep, when monoaminergic drive is withdrawn, excitability decreases, thus helping to ensure a relaxed motor state. Monoaminergic input from the brain stem can adjust the gain of the motor unit pool to suit the demands of different tasks. This flexibility does not compromise the size principle of orderly recruitment because the threshold for activation of the persistent inward currents is lowest in the motor neurons of slower motor units, which are the first recruited even in the absence of monoamines.	由于一元胺对运动神经元的特性影响较大，因此支配单个肌肉的运动神经元池的兴奋性受脑干的控制。对于慢收缩运动单位的运动神经元，适度的单胺能输入能够促进自持续放电。这大概就是慢收缩运动单位为保持姿势而施加的持续力的来源。睡眠期间，单胺能输入停止，兴奋性降低，有助于确保放松的运动状态。来自脑干的单胺能输入可以调节运动单位池的增益，适应不同运动任务的要求。在慢收缩运动单位的运动神经元中，持续性内向电流的激活阈值最低，即使在没有单胺类物质的情况下，这些运动单位也是最先被募集的。因此，单胺能输入的灵活性对有序招募的大小原则并无影响。
Muscle Force Depends on the Structure of Muscle	**肌肉结构决定肌力**
Muscle force depends not only on the amount of motor unit activity but also on the arrangement of the fibers in the muscle. Because movement involves the controlled variation of muscle force, the nervous system must take into account the structure of muscle to achieve specific movements.	肌力不仅取决于运动单位的活力，还取决于肌肉中纤维的排列方式。由于运动涉及肌肉力量的受控变化，要实现特定的运动，神经系统必须考虑肌肉的结构。
The Sarcomere Contains the Contractile Proteins	**肌节含有收缩蛋白**
Individual muscles contain thousands of fibers that vary from 1 to 500 mm in length and from 10 to	单个肌肉含有成千上万条纤维，其长度为 1~500 毫米，直径 10~60 微米。纤维

60μm in diameter. The variation in fiber dimensions reflects differences in the quantity of contractile protein. Despite this quantitative variation, the organization of contractile proteins is similar in all muscle fibers. The proteins are arranged in repeating sets of thick and thin filaments, each set known as a *sarcomere* (Figure 34-8). The physiological length of a sarcomere, which is bounded by Z disks, ranges from 1.5 μm to 3.5μm. Sarcomeres are arranged in series to form a *myofibril*, and the myofibrils are aligned in parallel to form a muscle fiber.	尺寸不同，收缩蛋白的数量也不同。尽管有这种数量上的差异，所有肌纤维中收缩蛋白的组织结构相似。蛋白质排列成一组组重复的粗、细肌丝，每一组称为一个*肌节*（图 34-8）。肌节的生理长度范围为 1.5 至 3.5 微米，由 Z 盘限定。肌节串联排列形成*肌原纤维*，肌原纤维平行排列构成肌肉纤维。
The force that each sarcomere can generate arises from the interaction of the contractile thick and thin filaments. The thick filament consists of a few hundred myosin molecules arranged in a structured sequence. Each myosin molecule comprises paired coiled-coil domains that terminate in two globular heads. The myosin molecules in the two halves of a thick filament point in opposite directions and are progressively displaced so that the heads, which extend away from the filament, protrude from the entire thick filament (Figure 34-8C). To maximize the interaction between the globular heads and the thin filaments, six thin filaments surround each thick filament.	每个肌小节所能产生的收缩力，来源于粗、细肌丝的相互作用。粗肌丝由几百个肌球蛋白分子组成，所有肌球蛋白分子按结构化序列排列。每个肌球蛋白分子由成对的卷曲螺旋结构域构成，其末端是两个球状的头。粗肌丝两端的肌球蛋白分子指向相反的方向，并逐渐移位，使得远离肌丝的头部突出于整个粗肌丝（图 34-8C）。为了最大限度地发挥球状头和细肌丝之间的相互作用，每条粗肌丝周围有 6 条细肌丝。
The primary components of the thin filament are two helical strands of fibrous F-actin, each of which contains approximately 200 actin monomers. Superimposed on F-actin are tropomyosin and	细肌丝的主要成分是两条螺旋的纤丝状肌动蛋白，每条都含有大约 200 个肌动蛋白单体。原肌球蛋白和肌钙蛋白叠加在纤丝状肌动蛋白上，是控制肌动

troponin, proteins that control the interaction between actin and myosin. Tropomyosin consists of two coiled strands that lie in the groove of the F-actin helix; troponin is a small molecular complex that is attached to tropomyosin at regular intervals (Figure 34-8C).	蛋白和肌球蛋白之间相互作用的蛋白质。原肌球蛋白由两条螺旋链构成，两条螺旋链位于纤丝状肌动蛋白螺旋槽中。肌钙蛋白是一种小分子复合物，按固定的间隔附着在原肌球蛋白上（图 34-8C）。
The thin filaments are anchored to the Z disk at each end of the sarcomere, whereas the thick filaments occupy the middle of the sarcomere (Figure 34-8B). This organization accounts for the alternating light and dark bands of striated muscle (Figure 34-8A). The light band contains only thin filaments, whereas the dark band contains both thick and thin filaments. When a muscle is activated, the width of the light band decreases, but the width of the dark band does not change, suggesting that the thick and thin filaments slide relative to one another during a contraction. This led to the *sliding filament hypothesis* of muscle contraction proposed by A.F. Huxley and H.E. Huxley in the 1950s.	细肌丝固定在肌节两端的 Z 盘上，粗肌丝则占据了肌节的中部（图 34-8）。该组织结构解释了为什么横纹肌的颜色明暗交替（图 34-8A）。明带只有细肌丝，暗带既有细肌丝也有粗肌丝。肌肉被激活时，明带宽度减少，暗带的宽度则无变化，这表明在收缩过程中，粗、细肌丝相互滑行。20 世纪 50 年代，A.F. HuxIey 和 H.E. Huxley 由此提出了*肌丝滑行学说*。
The sliding of the thick and thin filaments is triggered by the release of Ca^{2+} within the sarcoplasm of a muscle fiber in response to an action potential at the fiber's membrane, the sarcolemma. Varying the amount of Ca^{2+} in the sarcoplasm controls the interaction between the thick and thin filaments. Under resting conditions the Ca^{2+} concentration in the sarcoplasm is kept low by active pumping of Ca^{2+} into the sarcoplasmic reticulum, a network of	动作电位到达肌纤维膜（肌膜）后，钙离子进入到肌纤维肌浆，触发了粗细肌丝相互滑行。肌浆中钙离子量的变化控制粗细肌丝之间的相互作用。静息条件下，通过将钙离子主动泵入肌质网（即纵小管和光面内质网腔），肌浆中的钙浓度保持较低水平（图 34-8A）。钙被存储于终池，位于肌膜（横小管）的管腔膨大部分附近。横小管、终池和

longitudinal tubules and chambers of smooth endoplasmic reticulum (Figure 34-8A). Calcium is stored in the terminal cisternae, which are located next to intracellular extensions of the sarcolemma known as transverse tubules. The transverse tubules, terminal cisternae, and sarcoplasmic reticulum constitute an activation system that transforms an action potential into the sliding of the filaments.	肌质网共同构成了一个激活系统，将动作电位转化为肌丝滑行。
As an action potential propagates along the sarcolemma it invades the transverse tubules and causes the rapid release of Ca^{2+} from the terminal cisternae into the sarcoplasm. Once in the sarcoplasm Ca^{2+} diffuses among the filaments and binds reversibly to troponin, which results in the displacement of the troponin- tropomyosin complex and activates the sliding of the thick and thin filaments. Because a single action potential is insufficient to release enough Ca^{2+} to bind all available troponin sites in skeletal muscle, the strength of a contraction increases with the action potential rate.	沿肌膜传播时，动作电位侵入横小管，导致终池中的钙离子迅速释放到肌质中。一旦进入肌质，钙离子在肌丝间扩散，并与肌钙蛋白进行可逆性结合，从而导致肌钙蛋白—原肌球蛋白复合物移位，激活粗细肌丝滑行。单个动作电位不足以释放足够的钙离子，无法结合骨骼肌中所有可用的肌钙蛋白位点，因此，收缩的强度随着动作电位率的增加而增加。

The sliding of the filaments depends on mechanical work performed by the globular heads of myosin, work that uses chemical energy contained in adenosine triphosphate (ATP). The actions of the myosin heads are regulated by the *cross bridge cycle*, a sequence of detachment, activation, and attachment (Figure 34-9). In each cycle a globular head undergoes a displacement of 5 to 10 nm. Contractile activity continues as long as Ca^{2+} and ATP are present in the cytoplasm in sufficient amounts.	肌丝滑行取决于肌球蛋白球状头所做的机械功，腺苷三磷酸（ATP）中的化学能为此机械功助力。肌球蛋白头部的动作受*横桥周期*的调节，这是一个分离、激活和附着的序列（图 34-9）。每个循环中，一个球状头位移 5~10 纳米。只要胞质中有足够的钙离子和 ATP，收缩活动就会持续进行。
Figure 34-8 (Opposite) The sarcomere is the basic functional unit of muscle. (Adapted, with permission, from Bloom and Fawcett 1975 and from Patel and Lieber 1997.)	**图 34-8** （相反）肌节是肌肉的基本功能单位。（经许可，改编自 1975 年 Bloom 和 Fawcett ，以及 1997 年 Patel 和 Lieber 。）
A. This section of a muscle fiber shows its anatomical organization. Several myofibrils lie side-by-side in a fiber, and each myofibril is made up of sarcomeres arranged end-to-end and separated by Z disks (see part B). The myofibrils are surrounded by an activation system that includes the transverse tubules, terminal cisternae, and sarcoplasmic reticulum.	**A.** 该部分肌肉纤维展示了其解剖组织。几个肌原纤维并排排列在一根纤维中，每个肌原纤维由首尾相连的肌节组成，每个肌节被 Z 盘分隔开（见图 B）。肌原纤维被激活系统包围，该系统包括横小管、终末池和肌浆网。

B. Sarcomeres are connected to one another and to the muscle fiber membrane by the cytoskeletal lattice. The cytoskeleton influences the length of the contractile thick and thin filaments, maintains the alignment of these filaments within a sarcomere, connects adjacent myofibrils, and transmits force to the extracellular matrix of connective tissue through costameres. The consequence of this organization is that the force exerted by the contractile elements in a sarcomere can be transmitted along and across sarcomeres (through desmin and skelemin), within and between sarcomeres (through nebulin and titin), and to the costameres. The Z disk is a focal point for many of these connections.	**B.** 肌节相互连接，并与肌肉纤维膜通过细胞骨架相连。细胞骨架影响可收缩的粗细肌丝的长度，维持这些细丝在肌节内的排列，连接相邻的肌原纤维，并通过肋节将力传递到结缔组织的细胞外基质。有了这样的组织结构，肌节中可收缩肌丝施加的力可以（通过结蛋白和骨骼蛋白）沿着肌节传送并穿过肌节，可以（通过伴肌动蛋白和肌连蛋白）在肌节内和肌节之间传送，还可以传送至肋节。Z 盘是其中许多连接处的焦点。
C. The thick and thin filaments consist of various contractile proteins. The thin filament includes polymerized actin along with the regulatory proteins tropomyosin and troponin. The thick filament is an array of myosin molecules; each molecule includes a stem that terminates in a double globular head, which extends away from the filament.	**C.** 粗细肌丝由各种收缩蛋白质组成。细肌丝包括聚合肌动蛋白以及原肌球蛋白调节蛋白和肌钙蛋白。粗肌丝是由肌球蛋白分子排列而成的；每个分子都有一个两端为球状头部的茎，这两个球状头部向两端延伸。
Figure 34-9 The cross bridge cycle.	**Figure34-9** 横桥周期.
Several nonactivating states are followed by several activating states triggered by Ca^{2+}. The cycle begins at the top (**step 1**) with the binding of adenosine triphosphate (ATP) to the myosin head. The myosin head detaches from actin (**step 2**), ATP is hydrolyzed to phosphate (P_i) and ADP (**step 3**), and the myosin becomes weakly bound to actin (**step 4**). The binding	几个非激活状态之后紧接着是由 Ca^{2+}触发的几个激活状态。周期从顶部开始： **1.** 三磷酸腺苷（ATP）与肌球蛋白头结合。 **2.** 肌球蛋白头与肌动蛋白分离。 **3.** ATP 水解为磷酸（P_i）和 ADP。 **4.** 肌球蛋白与肌动蛋白弱结合。

of Ca^{2+} to troponin causes tropomyosin to slide over actin and enables the two myosin heads to close (**step 5**). This results in the release of P_i and the extension of the myosin neck, the power stroke of the cross bridge cycle (**step 6**). Each cross bridge exerts a force of about 2 pN during a structural change (step 7) and the release of adenosine diphosphate (ADP) (**step 8**). (•, strong binding; ~, weak binding; **M**^{f}, cross bridge force of myosin; and **M**^{f*}, force-bearing state of myosin.)	**5.** Ca^{2+}与肌钙蛋白结合，导致原肌球蛋白在肌动蛋白上滑动，并使两个肌球蛋白头闭合。 **6.** 上一步导致 P_i 被解离，肌球蛋白颈向桥臂方向扭动，即横桥周期的动力冲程。 **7.** 上述构象改变期间，每个横桥施加大约 2pN 的力。 **8.** ADP 被解离。 （**•**：强结合；~：弱结合；**M**^{f}：肌球蛋白横桥力；　**M**^{f*}：肌球蛋白的受力状态。）
(Adapted, with permission, from Gordon, Regnier, and Homsher 2001.)	（经许可，改编自 2001 年 Gordon、Regnier 和 Homsher。）
Noncontractile Elements Provide Essential Structural Support	**非收缩元素提供必要的结构支撑**
Structural elements of the muscle fiber maintain the alignment of the contractile proteins within the fiber and facilitate the transmission of force from the sarcomeres to the skeleton. A network of proteins (nebulin, titin) maintains the orientation of the thick and thin filaments within the sarcomere, whereas other proteins (desmin, skelemins) constrain the lateral alignment of the myofibrils (Figure 34-8B). These proteins contribute to the elasticity of muscle and maintain the appropriate alignment of cellular structures when the muscle is loaded.	肌肉纤维的结构元件维持着纤维内收缩蛋白的排列，并促进力量从肌节传递到骨架。蛋白质网（伴肌动蛋白，肌连蛋白）维持肌节内粗细肌丝的方向，其他蛋白质（结蛋白，骨架蛋白）制约肌原纤维横向排列（图 34-8B）。这些蛋白质有助于提高肌肉的弹性，并在肌肉受力时保证细胞结构适当排列。

Although some of the force generated by the cross bridges is transmitted along the sarcomeres in series, some travels laterally from the thin filaments to an extracellular matrix that surrounds each muscle fiber, through a group of transmembrane and membrane-associated proteins called a *costamere* (Figure 34-8B). The lateral transmission of force follows two pathways through the costamere and other through vinculin and members of the integrin family. Mutations of genes that encode components of the dystrophin-glycoprotein complex cause muscular dystrophies in humans.	尽管一些横桥产生的力是沿着肌节串联传递的，但是一些力通过一组穿膜蛋白和膜结合蛋白（*肋节*），从细肌丝横向传递到环绕每个肌肉纤维的细胞外基质（图 34-8B）。力的横向传递有两条途径，一是通过肋节，二是通过黏着斑蛋白和整合素家族成员。负责编码肌养蛋白—糖蛋白复合物成分的基因发生突变，会导致人类肌营养不良。
Contractile Force Depends on Muscle Fiber Activation, Length, and Velocity	**肌纤维的激活、长度和速度决定收缩力**
The force that a muscle fiber can exert depends on the number of cross bridges formed and the force produced by each cross bridge. These two factors are influenced by the Ca^{2+} concentration in the sarcoplasm, the amount of overlap between the thick and thin filaments, and the velocity with which the thick and thin filaments slide past one another. The influx of Ca^{2+} that activates formation of the cross bridges is transitory because continuous pump activity quickly returns Ca^{2+} to the sarcoplasmic reticulum. The release and reuptake of Ca^{2+} in response to a single action potential occurs so quickly that only some of the potential cross bridges are formed. This explains why the peak force of a twitch is less than the maximal force of the muscle fiber (see	肌肉纤维所能发挥的力取决于横桥的数量和每个横桥产生的力。这两个因素受以下三点影响：肌质中 Ca^{2+}浓度，粗细肌丝重叠量以及粗细肌丝相互滑行的速度。Ca^{2+}流入促进了横桥形成，但这只是短暂的，因为持续的泵活动很快将 Ca^{2+}送回肌质网。一个动作电位导致 Ca^{2+}的释放和再摄取，这一过程发生得极快，以至于仅形成少量电位横桥。这就解释了为什么收缩的峰值力小于肌肉纤维的最大力（见图 34-2A）。只有通过一系列动作电位，维持肌质中 Ca^{2+}浓度，才能实现最大力，从而最大限度地生成横桥。

Figure 34-2A). Maximal force can be achieved only with a series of action potentials that sustains the Ca^{2+} concentration in the sarcoplasm, thus maximizing cross bridge formation.	
Although Ca^{2+} activates formation of the cross bridges, cross bridges can be formed only when the thick and thin filaments overlap. This overlap varies as the filaments slide relative to one another (Figure 34-10A). At an intermediate sarcomere length (L_o) the amount of overlap between actin and myosin is optimal, and the relative force is maximal. Increases in sarcomere length reduce the overlap between actin and myosin and the force that can be developed. Decreases in sarcomere length cause the thin filaments to overlap, reducing the number of binding sites available to the myosin heads. Although many muscles operate over a narrow range of sarcomere lengths (approximately 94 ±13% L_o, mean ± SD), among muscles there is considerable diversity in sarcomere lengths during movement.	虽然 Ca^{2+}促进了横桥的形成，但只有粗肌丝和细肌丝重叠时才能才形成横桥。这种重叠随着肌丝的相对滑行而变化（图 34-10A）。肌节中等长度（L_o）时，肌动蛋白和肌球蛋白的重叠程度最佳，相对力最大。肌节长度增加，肌动蛋白和肌球蛋白的重叠减少，产生的力也减少。肌节长度减少，细肌丝重叠，肌球蛋白头可结合位点数量减少。虽然许多肌肉的肌节长度范围很窄（约 94+13%L_o，平均+SD），但在运动过程中，肌肉之间肌节长度存在相当大的差异。

Because structures that connect the contractile proteins to the skeleton also influence the force that a muscle can exert, muscle force increases with length over its operating range. This property enables muscle to function like a spring and to resist changes in length. Muscle stiffness, which corresponds to the slope of the relation between muscle force and muscle length (N/m), depends on the structure of the muscle. A stiffer muscle, like a stronger spring, is more resistant to changes in length.	连接收缩蛋白和骨架的结构也会影响肌肉可施加的力，因此在其工作范围内，肌力随长度增加而增加。这一特性使肌肉能像弹簧一样发挥作用，并能抵抗长度变化造成的影响。肌肉硬度相当于肌力和肌肉长度（N/m）的斜率，取决于肌肉的结构。一个较强的肌肉就像一个弹性较强的弹簧，对长度变化的抵抗力更强。
Once activated, cross bridges perform work and cause the thick and thin filaments to slide relative to one another. Because of the elasticity of intermediate-length filaments and the extracellular matrix, sarcomeres can shorten even when the length of the muscle fiber is held fixed. The direction and rate of change in sarcomere length depend on the amount of force relative to the magnitude of the load against which the sarcomere acts. Sarcomere length decreases when the force exceeds the load (*shortening contraction*) but increases when the force is less than the load (*lengthening contraction*). The maximal force that a muscle fiber can exert decreases as shortening velocity increases but increases as lengthening velocity increases (Figure 34-10B).	一旦激活，横桥执行工作，粗细肌丝相对于彼此滑行。由于中长肌丝和细胞外基质的弹性，即使肌纤维的长度保持不变，肌节也能缩短。肌节长度的方向和变化速率取决于作用在肌节上的力与所对抗的负载大小之间的比例。肌节长度在力超过负荷时减少（*缩短收缩*），但在力小于负荷时增加（*拉长收缩*）。缩短速度增加，肌纤维的最大力减少，拉长速度增加，最大力增加（图34-10B）。

The maximal rate at which a muscle fiber can shorten is limited by the peak rate at which cross bridges can form. The variation in fiber force as contraction velocity changes is largely caused by differences in the average force exerted by each cross bridge. For example, the decrease in force during a shortening contraction is attributable to a reduction in cross bridge displacement during each power stroke and the failure of some myosin heads to find attachment sites. Conversely, the increase in force during a lengthening contraction reflects the stretching of incompletely activated sarcomeres and the more rapid reattachment of cross bridges after they have been pulled apart.	横桥形成的峰值速度限制肌肉纤维缩短的最快速度。收缩速度发生变化时，纤维力的变化很大程度上是由各横桥施加的平均力的差异引起的。例如，缩短收缩过程中，力的减少可归因于每次动力冲程期间横桥位移的减少，以及一些肌球蛋白头无法找到附着位点。相反，在拉长收缩过程中，力的增加反映了未完全激活的肌节进行拉伸，以及在横桥被拉开后更迅速地重新连接。
The rate of cross bridge cycling not only depends on contraction velocity, but also on the preceding activity of the muscle. For example, after a brief isometric contraction the rate increases. When a muscle is stretched while in this state, such as would occur during a postural disturbance, muscle stiffness enhanced, and the muscle is more effective at resisting the change in length. This property is known as *short-range stiffness*. Conversely, the cross bridge cycling rate decreases after shortening contractions, and the muscle does not exhibit short-range stiffness.	横桥周期的速率不仅取决于收缩速度，还取决于肌肉之前的活动。例如，在短暂的等长收缩之后，速率提高。当肌肉在这种状态下被拉伸，例如在姿势平衡障碍的情况下，肌肉刚度增强，这使得肌肉更有效地抵抗长度的变化。这一特性叫做*短程刚度*。相反的，缩短收缩后，横桥循环率降低，肌肉不会表现出短程刚度。
Figure 34-10 Contractile force varies with the change in sarcomere length and velocity.	**图 34-10** 收缩力随肌节长度和速度的变化而变化。
A. Change in length.	**A.** 长度变化

At an intermediate sarcomere length, L_o, the amount of overlap between actin and myosin is optimal and the relative force is maximal. When the sarcomere is stretched beyond the length at which the thick and thin filaments overlap (length a), cross bridges cannot form and no force is exerted. As sarcomere length decreases and the overlap of the thick and thin filaments increases (between lengths a and b), the force increases because the number of cross bridges increases. With further reductions in length (between lengths c and e) the extreme overlap of the thin filaments with each other occludes potential attachment sites and the force decreases.	肌节中等长度（L_o）时，肌动蛋白和肌球蛋白的重叠程度最佳，相对力最大。当肌节被拉伸至粗细肌丝无法重叠的长度（肌节长度 a）时，横桥就无法形成，也不会施加任何力。由于肌节长度的变短，粗肌丝和细肌丝的重叠部分增加（长度 a~b），横桥数量也随之增多，因此力变大。随着肌节长度的进一步减小（肌节长度 c~e），细肌丝彼此过度重叠，堵塞了潜在的附着位点，因此力减小。
B. Rate of change.	**B.** 变化速度
Contractile force varies with the rate of change in sarcomere length. Relative to the force that a sarcomere can exert during an isometric contraction (zero velocity), the peak force declines as the rate of shortening increases. At the maximal shortening velocity (V_{max}) muscle force reaches a minimum.	收缩力随肌节长度和速度的变化而变化。相对于肌节在等长收缩（速度 0）过程中可以施加的力，峰值力随着缩短速度的增加而下降。在最大缩短速度（V_{max}）时，肌肉力量最小。

In contrast, when the sarcomere is lengthened while being activated, the peak force increases to values greater than those during an isometric contraction. Shortening causes the myosin heads to spend more time near the end of their power stroke, where they produce less contractile force, and more time detaching, recocking, and reattaching, during which they produce no force. When the muscle is actively lengthened the myosin heads spend more time stretched beyond their angle of attachment and little time unattached because they do not need to be recocked after being pulled away from the actin in this manner.	相反，当肌节被激活而拉长时，峰值力不断增加，远远大于等长收缩时的值。缩短会导致肌球蛋白头力量冲程的末期停留时间较长，在这种情况下，横桥产生的收缩力较小，而花费在分离、再次反应和再次附着的时间更多，在这期间，横桥并不产生力。当肌肉被主动拉长时，肌球蛋白头的附着角度变大，需要更多时间扭动，但分离的时间变短，这是因为在这种情况下，肌球蛋白头与肌动蛋白分离后不需要重新反应。
Figure 34-11 Five commom arrangement of tendon and muscle. (Reproduced, with permission, from Alexander and Ker 1990.)	**图 34-11** 肌腱和肌肉的五种常见排列。（经许可，转载自 1990 年 Alexander 和 Ker。）
Muscle Torque Depends on Musculoskeletal Geometry	**肌肉骨骼几何决定肌肉力矩**
The anatomy of a muscle has a pronounced effect on its force capacity, range of motion, and shortening velocity. The anatomical features that influence function include the arrangement of the sarcomeres in each muscle fiber, the organization of the muscle fibers within the muscle, and the location of the muscle on the skeleton. These features vary widely among muscles (Figure 34-11).	肌肉的解剖结构对肌肉的承载力、运动范围和缩短速度有显著的影响。解剖特征影响肌肉功能，包括各肌肉纤维中的肌节排列、肌肉中肌纤维的组织以及肌肉在骨架上的位置。在不同的肌肉中这些特征差异很大（图 34-11）。

At the level of the single muscle fiber the number of sarcomeres in series and in parallel can vary. The number of sarcomeres in series determines the length of the myofibril and thus the length of the muscle fiber. Because one sarcomere can shorten by a certain length with a given maximal velocity, both the range of motion and the maximal shortening velocity of a muscle fiber are proportional to the number of sarcomeres in series. The force that a myofibril can exert is equal to the average sarcomere force and is not influenced by the number of sarcomeres in series. The force capacity of a fiber, however, depends on the number of sarcomeres in parallel and hence on the diameter or cross-sectional area of the fiber.	就单个肌纤维来说，串联和并联的肌节数量大不相同。串联的肌节数量决定了肌原纤维的长度，继而决定了肌纤维的长度。因为一个肌节在给定的最大速度下可以缩短一定长度，所以肌纤维的运动范围和最大缩短速度都与串联的肌节数量成正比。肌原纤维可以施加的力等于平均肌节力，并且不受串联肌节数量的影响。然而，纤维的承载力取决于并联肌节的数量，也就是取决于纤维的直径或横截面积。
At the level of the muscle, the functional attributes of the fibers are modified by the orientation of the fascicles to the line of pull of the muscle and the length of the fiber relative to the muscle length. In most muscles the fascicles are not parallel to the line of pull but fan out in feather-like (pennate) arrangements (Figure 34-11). The relative orientation, or pennation angle of the fascicles, ranges from 0 degrees (biceps brachii, sartorius) to approximately 30 degrees (soleus). Because more fibers can fit into a given volume as the pennation angle increases, muscles with large pennation angles typically have more myofibrils in parallel and hence large cross-sectional areas.	在肌肉层面，纤维的功能属性受以下两个因素影响：一是相对于肌肉牵拉线的肌束方向，二是相对于肌肉长度的纤维长度。在大多数肌肉中，肌束与肌肉牵拉线不平行，而是呈羽毛状（羽状）排列（图 34-11）。肌束的相对方向或羽状角范围从 0 度（肱二头肌，缝匠肌）到大约 30 度（比目鱼肌）。随着羽状角扩大，更多的纤维可以纳入给定的体积，因此羽状角大的肌肉通常具有更多平行的肌原纤维，也就具有较大的横截面积。

Given the linear relation between cross-sectional area and maximal force (~0.25 N·mm^{-2}), these muscles are capable of a greater maximal force. However, the fibers in pennate muscles are generally short and have a lesser maximal shortening velocity than those in nonpennate muscles.	鉴于横截面积和最大力（~0.25N·mm^{-2}）之间的线性关系，这些肌肉的最大力可以更大。然而，羽状肌纤维一般较短，与非羽状肌纤维相比，最快缩短速度也较小。
The functional consequences of this anatomical arrangement can be seen by comparing the contractile properties of two muscles with different numbers of fibers and fiber lengths. If the two muscles have identical fiber lengths, but one has twice as many fibers, the range of motion of the two muscles will be similar because it is a function of fiber length, but the maximal force capacity will vary in proportion to the number of muscle fibers. If the two muscles have identical numbers of fibers but the fibers in one muscle are twice as long, the muscle with the longer fibers will have a greater range of motion and a greater maximal shortening velocity, even though the two muscles have a similar force capacity. Because of this effect, the muscle with longer fibers is able to exert more force and produce more power (the product of force and velocity) at a given absolute shortening velocity (Figure 34-12).	两块纤维数量和长度都不同的肌肉，通过比较他们的收缩特性，可以得到这种解剖结构的功能性结果。如果两块肌肉的纤维长度相同，但其中一块的纤维数量是另一块的两倍，那么这两块肌肉的运动范围相似，因为运动范围由纤维长度决定，但最大承载力与肌肉纤维的数量成正比。如果两块肌肉的纤维数量相同，但其中一块肌肉的纤维长度是另一块的两倍，那么即使他们的承载力相似，前者的运动范围更大，最快缩短速度更快。由于这一效应，纤维较长的肌肉在给定的绝对缩短速度下能发挥更大的力，产生更大的功率（力和速度的乘积）（图 34-12）。
Figure 34-12 Muscle dimensions influence the peak force and maximal shortening velocity. (Reproduced, with permission, from Lieber and Fridén 2000.)	**图 34-12** 肌肉尺寸影响峰值力和最快缩短速度。（经许可，转载自 2000 年 Lieber 和 Fridén。）

A. Muscle force at various muscle lengths for two muscles with similar fiber lengths but different numbers of muscle fibers (different cross-sectional area). The muscle with twice as many fibers exerts greater force.	**A.** 纤维长度相似，但肌肉纤维数量不同（横截面积不同）的两块肌肉，在不同肌肉长度下的肌力。纤维数量更多的肌肉（是另一块肌肉的两倍）会施加更大的力。
B. Muscle force at various muscle lengths for two muscles with the same cross-sectional area but different fiber lengths. The muscle with longer fibers (about twice as long as those of the other muscle) has an increased range of motion (left plot). It also has a greater maximal shortening velocity and exerts greater force at a given absolute velocity (right plot).	**B.** 横截面积相同，但纤维长度不同的两块肌肉，在不同肌肉长度下的肌力。 纤维较长的肌肉（大约是另一块肌肉的两倍），其运动范围（左图）、最快缩短速度以及在给定的绝对速度下施加的力（右图）都比另一块肌肉大。
Muscle fiber lengths and cross-sectional areas vary substantially throughout the human body, which suggests that the contractile properties of individual muscles also differ markedly. In the leg, for example, fiber length ranges from 20 mm (soleus) to 460 mm (sartorius), and cross-sectional area ranges from 200 mm2 (sartorius) to 5800 mm^2 (soleus). Functionally coupled muscles tend to have complementary combinations of these properties. For example, muscles characterized by large pennation angles, large cross-sectional areas, and short fibers (quadriceps femoris) are often functionally coupled with those that have smaller cross-sectional areas and longer fibers (hamstrings).	在整个人体中，肌肉纤维的长度和横截面积差异很大，这表明个别肌肉的收缩特性也明显不同。以腿部为例，纤维长度范围从 20mm（比目鱼肌）到 460mm（缝匠肌），横截面积范围从 200mm^2（缝匠肌）到 5800mm^2（比目鱼肌）。功能耦合肌肉中，这些特性往往互补组合。例如，有的肌肉羽状角大，横截面积大，纤维短（股四头肌），有的肌肉横截面积小，纤维较长（绳肌腱），他们往往在功能上耦合。

Movement is the muscle-controlled rotation of adjacent body segments, which means that the capacity of a muscle to contribute to a movement also depends on its location relative to the joint that it spans. The rotary force exerted by a muscle about a joint is referred to as *muscle torque* and is calculated as the product of the muscle force and the *moment arm*, the shortest perpendicular distance from the line of pull of the muscle to the joint's center (Figure 34-13).	运动就是肌肉控制相邻身体节段进行旋转，这意味着肌肉对运动的贡献能力也取决于其相对于所跨关节的位置。肌肉对关节施加的旋转力被称作*肌力矩*，其计算方法是肌力×*矩臂*，矩臂是肌肉牵拉线到关节中心的最短垂直距离（图 34-13）。
Figure 34-13 Muscle torque varies over a joint's range of motion.	**图 34-13** 肌力矩随关节的运动范围而变化。
A muscle exerts a torque about a joint that is the product of its contractile force (F) and its moment arm at the joint (d). The moment arm is the shortest perpendicular distance from the line of pull of the muscle to the joint's center of rotation. Because the moment arm changes when the joint rotates, muscle torque varies with angular displacement about the joint. The net torque about a joint, which determines the mechanical action, is the difference in the torques exerted by opposing muscles, such as extensors (ext) and flexors (flex). Similarly, a force applied to the limb (F_{load}) will exert a torque about the joint that depends on F_{load} and its distance from the joint (d_{seg}).	肌肉围绕关节施加扭矩，该扭矩是其收缩力（F）和其在关节处的矩臂（d）的乘积。矩臂是从肌肉牵拉线到关节旋转中心的最短垂直距离。当关节旋转时，矩臂随之发生变化，所以肌力矩会随着关节的角位移而变化。关节处的净扭矩决定机械作用，是伸肌（exts）和屈肌（flex）等对抗肌肉施加的扭矩的差值。类似地，施加在肢体上的力（F_{load}）将围绕关节施加力矩，该力矩大小取决于 F_{load} 及其与关节的距离（d_{seg}）。

The moment arm usually changes as a joint rotates through its range of motion; the amount of change depends on where the muscle is attached to the skeleton relative to the joint. If the force exerted by a muscle remains relatively constant throughout the joint's range of motion, muscle torque varies in direct proportion to the change in the moment arm. For many muscles the moment arm is maximal in the middle of the range of motion, which usually corresponds to the position of maximal muscle force and hence greatest muscle torque.	矩臂通常随着关节在其运动范围内的旋转而变化；变化量取决于肌肉相对于关节附着在骨骼上的位置。如果肌肉施加的力在整个关节的运动范围内保持相对恒定，那么肌力矩的变化与矩臂成正比。对于许多肌肉来说，关节处于运动范围的中间位置时，矩臂最大，这个位置通常也是肌力最大的时候，因此，此时的肌力矩最大。
Different Movements Require Different Activation Strategies	**不同的运动需要不同的激活策略**
The human body has approximately 600 muscles, each with a distinct torque profile about one or more joints. To perform a desired movement the nervous system must activate an appropriate combination of muscles with adequate intensity and timing of activity. The activation must be appropriate for the contractile properties and musculoskeletal geometry of many muscles, as well as the mechanical interactions between body segments. As a result of these demands, activation strategies differ with the details of the movement.	人体有大约 600 个肌肉，每个肌肉在与一个或多个关节相连时都有不同的扭矩特性。为了完成所需运动，神经系统必须激活一组合适的肌肉，确保这些肌肉的活动有足够的强度和合适的时机。这一过程必须适应多种肌肉的收缩特性和肌肉骨骼几何，还要考虑身体各部分之间的力学相互作用。由于这些必要条件，激活策略因运动的细节而异。
Contraction Velocity Can Vary in Magnitude and Direction	**收缩大小和方向不同，收缩速度不同**

Movement speed depends on the contraction velocity of a muscle. The only ways to vary contraction velocity are to alter either the number of motor units recruited or the rates at which they discharge action potentials. The velocity of a contraction can vary in both magnitude and direction (see Figure 34-10B). To control the velocity of a contraction the nervous system must scale the magnitude of the net muscle torque relative to the load torque, which includes both the weight of the body segment and any load applied externally to the body.	运动速度取决于肌肉的收缩速度。改变收缩速度的唯一方法是改变运动单位募集数量或改变其释放动作电位的速度。收缩大小和方向不同，收缩速度不同（见图 34-10B）。为了控制收缩的速度，神经系统必须根据负荷力矩来调节净肌力矩的大小，负荷力矩包括人体环节的重量和施加在身体外部的任何负荷。
When muscle torque exceeds load torque, the muscle shortens as it performs a shortening contraction. When muscle torque is less than load torque, the muscle lengthens as it performs a lengthening contraction. For the example shown in Figure 34-13, the load is lifted with a shortening contraction of the flexor and lowered with a lengthening contraction. Both types of contractions are common in daily activities. Shortening and lengthening contractions are not simply the result of adjusting motor unit activity so that the net muscle torque is greater or less than the load torque. When the task involves lifting a load with a prescribed trajectory, activation of the motor units must be aligned so that the summed rise times match the desired trajectory during the shortening contraction, whereas the lengthening contraction requires that the summed decay times be matched.	当肌力矩超过负荷力矩时，肌肉进行缩短收缩，长度缩短。当肌力矩小于负荷力矩时，肌肉进行拉长收缩，长度拉长。如图 34-13 所示，屈肌缩短收缩，负荷提升；屈肌拉长收缩，负荷降低。这两种收缩类型在日常活动中很常见。 调节运动单位活动（使净肌肉矩大于或小于负荷扭矩）不仅仅是为了缩短和拉长收缩。当活动任务涉及按规定的轨迹提升负载时，必须对应激活运动单位，以便在缩短收缩过程中总的上升时间与期望的轨迹相匹配，而拉长收缩则要求总的衰减时间与期望的轨迹相匹配。

The nervous system accomplishes this by varying the descending input and sensory feedback during the two contractions. Because of these differences, some people, such as older adults and persons performing rehabilitation exercises after an orthopedic procedure, have greater difficulty performing lengthening contractions.	在这两种收缩过程中，神经系统通过改变下行输入和感觉反馈，来实现这一目标。由于这些差异，一些人的肌肉很难进行拉长收缩，如老年人和骨科手术后康复锻炼的人。
The amount of motor-unit activity relative to the load also influences the contraction velocity. This effect depends on both the number of motor units recruited and the maximal rates at which the motor units can discharge action potentials. For example, the maximal rate of increase in muscle torque during a submaximal contraction increases after several weeks of physical training and is associated with a marked increase in the initial discharge rates of the activated motor units. Physical training increases the rate at which motor units can discharge trains of action potentials, an effect that can be mimicked by the rapid injection of current into a motor neuron. Changes in the maximal shortening velocity of a muscle after a change in the habitual level of physical activity are the result, at least partly, of factors that influence the ability of motor units to discharge action potentials at high rates.	相对于负荷而言，运动单位的活动量也会影响收缩速率。这种影响取决于运动单位的募集数量和运动单位可以释放动作电位的最大速度。例如，经过几周的体能训练后，次最强收缩时，肌力矩的最大增长率提高，被激活运动单位的初始放电速度明显提升。体能训练提高了运动单位释放动作电位序列的速度，通过向运动神经元快速注入电流可以模拟这种效果。习惯性体力活动水平发生变化后，肌肉最快缩短速度也发生变化，这多少是由于运动单位高速释放动作电位的能力受到影响。
Movements Involve the Coordination of Many Muscles	**运动涉及多种肌肉的协调合作**

To achieve a prescribed trajectory the nervous system must activate not only the muscles that produce the desired displacement but also muscles that prevent unintended actions. For example, the elbow flexor muscles are used to rapidly rotate the forearm about the elbow joint. But unless the muscles that cross the wrist are also activated to stabilize the wrist joint, rotation of the forearm would cause the hand to flail about the wrist joint.	为了实现规定的运动轨迹，神经系统不仅要激活能够实现所需位移的肌肉，还要激活相应的肌肉防止意外动作。例如，肘屈肌能让前臂围绕肘关节快速旋转。但是，横跨手腕的肌肉也要被激活以稳定腕关节，否则前臂的旋转会导致手围绕腕关节摆动。
In the simplest case muscles span a single joint and cause the attached body segments to accelerate about a single axis of rotation (Figure 34-14A). Because muscles can exert only a pulling force, motion about a single axis of rotation requires at least two muscles or groups of muscles. Thus, the flexion-extension motion about the knee joint involves the hamstring muscles to exert force in the direction of flexion and the quadriceps to exert force in the direction of extension.	在最简单的情况下，肌肉跨越单个关节，使附着的人体环节围绕一个轴加速旋转（图 34-14A）。肌肉只能施加一个拉力，因此围绕单个旋转轴的运动至少需要两块或一组肌肉。因此，围绕膝关节的屈伸运动需要绳肌腱向屈曲方向施力，股四头肌向伸展方向施力。
However, many muscles attach to the skeleton slightly off center and can cause movement about more than one axis of rotation. If one of the actions is not required, the nervous system must activate other muscles to control the unwanted movement. For example, activation of the radial flexor muscle of the wrist can cause the wrist to flex and abduct.	然而，许多肌肉附着在骨架上的位置略微偏离中心，并且可以带动人体环节围绕多个旋转轴运动。如果其中一个运动是不需要的，神经系统必须激活其他肌肉来控制这一运动。例如，激活桡侧腕屈肌可以带动手腕的外展与内收。

If the intended action is only wrist flexion, then the abduction action must be opposed by another muscle, such as the ulnar flexor muscle, which causes wrist flexion and adduction. Depending on the geometry of the articulating surfaces and the attachment sites of the muscles, the multiple muscles that span a joint are capable of producing movements about one to three axes of rotation. Furthermore, some structures can be displaced linearly (eg, the scapula on the trunk), adding to the degrees of freedom about a joint.	如果预期的动作只是腕部屈曲，那么外展动作必须由另一块肌肉（如尺屈肌，带动腕部外展和内收）来对抗。依据关节面的几何形状和肌肉的附着部位，跨越同一个关节的多个肌肉能够带动人体环节围绕 1~3 个旋转轴运动。此外，一些结构可以线性位移，（如躯干上的肩胛骨），增强关节的灵活度。
This organization enhances the flexibility of the skeletal motor system, for the same movement can be achieved by activating different combinations of muscles. However, this additional flexibility comes with a cost in the corresponding variation in the unwanted actions that must be controlled. A solution used by the nervous system is to organize relations among selected muscles to produce specific actions. A particular balance of muscle activations that changes over time is known as a muscle synergy, and movement is produced through the coordinated activation of these synergies. For example, electromyographic recordings suggest that a range of human movements, such as grasping objects with the hand, reaching and pointing in different directions, and walking and running at several speeds, are controlled by approximately five muscle synergies.	这样的组织结构增强了骨骼运动系统的灵活性，同一运动可以通过激活不同的肌肉组合来实现。然而，这种额外的灵活性是有成本的——神经系统必须控制额外动作导致的相应变化。为此，神经系统的解决方法是在选定的肌肉中建立相应的联系，产生特定的动作。肌肉激活的特定平衡随时间变化，该平衡被称作肌肉协同，运动就是通过激活这些协同作用产生的。例如，肌电数据表明，在大约五种肌肉的协同作用下，人类可以进行一系列运动，如用手抓物体、向不同方向伸手和指向、以多种速度行走和跑步。

The number of muscles that participate in a movement also varies with the speed of the movement. For example, slow lifting of the load shown in Figure 34-13 requires only that the muscle torque slightly exceed the load torque, and thus only the flexor muscle is activated. This strategy is used when lifting a handheld weight with the elbow flexor muscles. In contrast, to perform this movement rapidly with an abrupt termination, both the flexor and extensor muscles must be activated. First the flexor muscle is activated to accelerate the limb in the direction of flexion, followed by activation of the extensor muscle to accelerate the limb in the direction of extension, and finally a burst of activity by the flexor muscle to reduce the angular momentum of the limb and the handheld weight in the direction of flexion so that it arrives at the desired joint angle (Figure 34-14B). The amount of extensor activity increases with the speed of the movement. Increases in movement speed introduce another factor that the nervous system must control; unwanted accelerations in other body segments. Because body segments are interconnected, motion in one segment can induce motion in another. At the beginning of the swing phase in running, for example, the hip flexor muscles are activated and accelerate the thigh in a forward direction (Figure 34-15A).	参与运动的肌肉数量也随运动的速度而变化。例如，图 34-13 所示的缓慢举重只要求肌力矩略微超过负荷力矩，因此只需激活屈肌。用肘屈肌举起手持重物时，采用的就是这一策略。相反，如果要快速进行该动作并突然终止，必须同时激活屈肌和伸肌。首先，激活屈肌，肢体向屈曲方向加速，接着激活伸肌，肢体向伸展方向加速，最后屈肌爆发，减小肢体和手持重物在屈曲方向的角动量，使其达到所需的关节角度（图 34-14B）。伸肌的活动量随着运动的速度而增加。 运动速度的增加导致神经系统必须控制另一个因素：其他人体环节不必要的加速。由于人体环节是相互关联的，某一环节的运动可以引起另一环节的运动。例如，跑步的迈步期开始时，髋屈肌被激活，大腿朝前加速（图 34-15A）。

The motion of the thigh causes the lower leg to rotate backward about the knee joint. To control the backward displacement of the lower leg, the quadriceps muscles are activated to accelerate the lower leg in the forward direction. As the lower leg rotates backward, the quadriceps muscles perform a lengthening contraction that becomes a shortening contraction to rotate the lower leg forward in the middle of the swing phase.	大腿的运动导致小腿围绕膝关节向后旋转。为了控制小腿向后位移，股四头肌被激活，小腿朝前加速。小腿向后旋转时，股四头肌拉长收缩，随后，该收缩变成缩短收缩，使得小腿在迈步期中途向前旋转。
Figure 34-14 Muscle torque must overcome inertia when a movement is started and stopped.	**图 34-14** 运动开始和停止时，肌力矩必须克服惯性。
A. According to Newton's law of acceleration (force = mass x acceleration), force is required to change the velocity of a mass. Muscles exert a torque to accelerate the inertial mass of the skeletal segment around a joint. For angular motion, Newton's law is written as torque = rotational inertia × angular acceleration.	**A.** 根据牛顿加速度定律（力=质量×加速度），需要力来改变质量的速度。肌肉施加扭矩来加速关节周围骨骼段的惯性质量。对于角运动，牛顿定律为扭矩=转动惯量×角加速度。
B. The angular velocity for movement of a limb from one position to another has a bell-shaped profile reflecting Newton's law of acceleration. Acceleration in one direction is followed by acceleration in the opposite direction--the flexor and extensor muscles are activated in succession.	**B.** 肢体从一个位置移动到另一个位置的角速度呈现钟形曲线分布，这反映了牛顿的加速度定律。一个方向的加速度紧跟着相反方向的加速度——屈肌和伸肌依次被激活。

The records here show the activation profiles and associated muscle torques for an elbow flexion movement. Because contractile force decays relatively slowly, the flexor muscle is usually activated a second time to counter the prolonged acceleration generated by the extensor muscle and to stop the limb exactly on target.	图中的记录显示了肘部屈曲运动时的激活曲线和相关的肌力矩。由于收缩力衰减相对较慢，屈肌通常会被第二次激活，以对抗伸肌产生的延长加速度，并使肢体完全停在目标位置上。
Figure 34-15 A single muscle can influence the motion about many joints.	**图 34-15** 一个肌肉可以影响许多关节的运动。
A. Muscles that cross one joint can accelerate an adjacent body segment. For example, at the beginning of the swing phase while running, the hip flexor muscles are activated to accelerate the thigh forward (red arrow). This action causes the lower leg to rotate backward (blue arrow) and the knee joint to flex.To control the knee joint flexion during the first part of the swing phase, the knee extensor muscles are activated and undergo a lengthening contraction to accelerate the lower leg forward (red arrow) while it continues to rotate backward (blue arrow).	**A.** 跨过同一个关节的肌肉可以加速相邻的人体环节。例如，跑步的迈步期开始时，髋屈肌被激活，大腿朝前加速（红色箭头）。大腿的运动导致小腿向后旋转（蓝色箭头），膝关节弯曲。为了在迈步初期控制膝关节屈曲，膝伸肌被激活，进行拉长收缩，使小腿向前加速（红色箭头），同时继续向后旋转（蓝色箭头）。

B. Many muscles cross more than one joint to exert an effect on more than one body segment. For example, the hamstring muscles of the leg accelerate the hip in the direction of extension and the knee in the direction of flexion (red arrows). At the end of the swing phase during running, the hamstring muscles are activated and undergo lengthening contractions to control the forward rotation of the leg (hip flexion and knee extension). This strategy is more economical than activating individual muscles at the hip and knee joints to control the forward rotation of the leg.	**B.** 许多肌肉跨过多个关节，对多个人体环节产生影响。例如，腿的腘绳肌使髋关节向伸展方向加速，使膝关节向屈曲方向加速（红色箭头）。在跑步的迈步期结束时，腘绳肌肉被激活并进行拉长收缩，以控制腿的向前旋转（髋关节屈曲，膝关节伸展）。与激活髋关节和膝关节的单个肌肉来控制腿的向前旋转相比，这种策略的效率更高。
Muscles that span more than one joint can be used to control the motion-dependent interactions between body segments. At the end of the swing phase in running, activation of the hamstring muscles causes both the thigh and lower leg to accelerate backward (Figure 34-15B). If a hip extensor muscle was used to accelerate the thigh backward instead of the hamstring muscles, the lower leg would accelerate forward, requiring activation of a knee flexor muscle to control the unwanted motion so that the foot could be placed on the ground.	跨越一个以上关节的肌肉可以用来控制人体环节之间运动依赖性相互作用。跑步的迈步期结束时，腘绳肌被激活，使大腿和小腿都向后加速（图 34-15B）。如果髋伸肌替代绳肌腱使大腿向后加速，小腿就会向前加速，这就需要激活膝屈肌，控制这一不需要的运动，使脚可以触地。

Use of the two-joint hamstring muscles is a more economical strategy, but one that can subject the hamstrings to high stresses during fast movements, such as sprinting. The control of such motion-dependent interactions often involves lengthening contractions, which maximize muscle stiffness and the ability of muscle to resist changes in length	利用双关节腘绳肌是一种更高效的策略，但在快速运动（如短跑）过程中，这会使腘绳肌承受高压。控制运动时的相互作用常涉及拉长收缩，拉长收缩最大限度地提高肌肉的硬度和抵抗长度变化的能力。
For most movements the nervous system must establish rigid connections between some body segments for two reasons. First, as expressed in Newton's law of action and reaction, a reaction force must provide a foundation for the acceleration of a body segment. For example, in a reaching movement performed by a person standing upright, the ground must provide a reaction force against the feet. The muscle actions that produce the arm movement exert forces that are transmitted through the body to the feet and are opposed by the ground. Different substrates provide different amounts of reaction force, so ice or sand substantially alter movement capabilities.	对于大多数运动，神经系统必须在部分人体环节之间建立刚性连接，原因有二。首先，根据牛顿的作用和反作用定律，反作用力一定为身体某一部分的加速提供基础。例如，一个直立的人做伸展运动时，地面一定提供一个对脚的反作用力。产生手臂运动的肌肉动作，其施加的力通过身体传递到脚，并与地面相对。地面不同，反作用力大小也不同，因此冰面或沙地会大大改变运动能力。

Second, uncertain conditions are usually accommodated by stiffening the joints through concurrent activation of the muscles that produce force in opposite directions. Coactivation of opposing muscles occurs often when a support surface is unsteady, when the body might experience an unexpected perturbation, or when lifting a heavy load. Because coactivation increases the energetic cost of performing a task, one characteristic of skilled performance is the ability to accomplish a task with minimal activation of muscles that span associated joints.	其次，为了适应不确定条件，通常需要同时激活产生相反方向力的肌肉，硬化关节。支撑面不稳定、身体遭遇意外扰动、举起重物，在这些情况下，对立的肌肉常常被同时激活。共同激活导致动作的完成需要更多能量，所以动作熟练有一个特征，那就是完成任务时，激活的跨相关关节肌肉数量最少。
Muscle Work Depends on the Pattern of Activation	**激活模式决定肌肉工作**
Limb muscles in healthy young adults are active 10% to 20% of the time during waking hours. For much of this time the muscles perform constant-length (*isometric*) contractions to maintain a variety of static body postures. In contrast, muscle length has to change during a movement so that the muscle can perform work to displace body segments. A muscle performs positive work and produces power during a shortening contraction, whereas it performs negative work and absorbs power during a lengthening contraction. The capacity of muscle to do positive work establishes performance capabilities, such as the maximal height that can be jumped.	在清醒状态下，健康年轻成人的四肢肌肉大约有 10%到 20%的时间处于活跃状态。大部分时间里，肌肉进行等长收缩，维持各种静态的身体姿势。相反，在运动过程中，肌肉的长度必须发生变化，这样肌肉才能移动人体环节。缩短收缩时，肌肉做正功，产生动力；拉长收缩时，肌肉做负功，吸收动力。肌肉做正功的能力决定运动能力，如跳跃的最大高度。

The nervous system enhances the work capacity of muscle by commanding a brief period of negative work before positive work. This activation sequence, the *stretch-shorten cycle*, occurs in many movements. When a person jumps in place on two feet, for example, the support phase involves an initial stretch and subsequent shortening of the ankle extensor and knee extensor muscles (Figure 34-16A). The forces in the Achilles and patellar tendons increase during the stretch and reach a maximum at the onset of the shortening phase. As a result, the muscles can perform more positive work and produce more power during the shortening contraction (Figure 34-16B).	神经系统命令肌肉在做正功前，先短暂地做负功，以此增强肌肉的作功能力。这种激活顺序，即拉长—缩短周期，在很多运动中都会发生。例如，一个人双脚原地跳跃时，支撑期包括最初的拉伸和随后的踝伸肌、膝伸肌缩短（图 34-16A）。拉伸过程中，跟腱和髌腱中的力增加，并在缩短阶段开始时达到最大值。因此，在缩短收缩期间，肌肉可以做更多的正功，产生更大的力量（图 34-16B）。
Figure 34-16 An initial phase of negative work enhances subsequent positive work performed by the muscle. (Reproduced, with permission, from Finni, Komi, and Lepola 2000 and from Gregor et al. 1988.)	**图 34-16** 负功的初始阶段会增强肌肉随后所做的正功。（经许可，转载自 2000 年 Finni, Komi 和 Lepola，1988 年 Gregor 等人）
A. The force in the Achilles tendon and patellar tendon vary during the ground-contact phase of two-legged hopping. The feet contact the ground at touchdown (TD) and leave the ground at toe-off (TO). For approximately the first half of the movement the quadriceps and triceps sure muscles lengthen, performing negative work (negative velocity). The muscles perform positive work when they shorten (positive velocity).	**A.** 在双脚跳跃的接地阶段，跟腱和髌腱中的力是不同的。TD，双脚接触地面，TO，双脚离开地面。大约在运动的前半段，股四头肌和三头肌的一定会拉长，做负功（负速度）。当肌肉缩短时，做正功（正速度）。

B. The force exerted by the soleus muscle of a cat running at moderate speed varies from the instant the paw touches the ground (TD) until it leaves the ground (TO). The force exerted by the muscle during the shortening contraction is greater than the peak forces measured when the muscle contracts maximally against various constant loads (isotonic loading). Negative velocity reflects a lengthening contraction in the soles muscle. The power produced by the soleus muscle of the cat during running is greater than that produced in an isolated-muscle experiment (**dashed line**). The phase of negative power corresponds to the lengthening contraction just after the paw is placed on the ground (TD), when the muscle performs negative work. Although negative work involves an increase in the length of the muscle, the length of the fascicles in the muscle often remains relatively constant, which indicates that the connective-tissue structures are stretched prior to the shortening contraction.	**B.** 以中等速度奔跑的猫，从爪子接触地面的那一刻（TD）到离开地面（TO），其比目鱼肌施加的力不断发生变化。肌肉在缩短收缩过程中施加的力大于对抗各种恒定载荷（等张力负载）最大收缩时的峰值力。负速度反映了足底肌肉的拉长收缩。猫在跑步过程中，比目鱼肌产生的力量大于孤立肌肉实验中产生的力量（**虚线**）。负速度的阶段对应爪子接触地面后的拉长收缩（TD），这时肌肉进行负功。尽管做负功时，肌肉拉长，但肌肉中神经束的长度往往保持相对恒定，这表明缩短收缩之前，结缔组织拉长。
Thus the capacity of the muscle to perform more positive work comes from strain energy that can be stored in the tendon during the stretch phase and released during the subsequent shortening phase. The ability of a muscle to benefit from this strategy depends on its morphological characteristics and is greatest in muscles with long tendons.	因此，肌肉做更多正功的能力来源于应变能，这种势能在拉伸阶段储存在肌腱中，并在随后的缩短阶段释放。肌肉从这一策略中获得的能力取决于其形态特征，肌腱越长，能力越强。
An Overall View	**本章小节**

Movement involves the coordinated interaction of the nervous system and muscle. The basic functional unit of motor control is the motor unit, which consists of a motor neuron and the muscle fibers that it innervates. The force exerted by a muscle depends in part on the number and properties of the motor units that are activated. These properties include contraction speed, maximal force, and fatigability, all of which can be altered by physical activity. The rate of firing in each active motor neuron is also a factor in muscle force. Motor units tend to be activated in a stereotypical order that is highly correlated with motor-neuron size.	运动涉及神经系统和肌肉的协调互动。运动单位是运动控制的基本功能单位，由一个运动神经元和其所支配的肌纤维组成。肌力大小部分取决于激活运动单位的数量和特性，包括收缩速度、最大力和疲劳性，通过体力活动可以改变运动单位的特性。每个活跃的运动神经元的放电速率也是影响肌力的一个因素。运动单位往往按照一种模式化顺序被激活，这种顺序与运动神经元的大小高度相关。
Muscle force depends not only on the characteristics of motor-unit activity, but also on the arrangement of the muscle fibers. The sarcomere is the smallest element of muscle to include a complete set of contractile proteins. A transient connection between the contractile proteins myosin and actin, known as the cross bridge cycle, enables muscle to exert a force. The organization of the sarcomeres within a muscle varies substantially and has a major effect on the contractile properties of the muscle.	肌力不仅取决于运动单位的募集特征，还取决于肌纤维的排列。肌节是最小的肌肉元素，包含一整套收缩蛋白质。肌球蛋白和肌动蛋白短暂结合，即横桥周期，使肌肉能够施力。肌肉内的肌节组织有很大差异，对肌肉的收缩特性有很大影响。

For a given arrangement of sarcomeres, the force a muscle can exert depends on the activation of the cross bridges by Ca^{2+}, the amount of overlap between the thick and thin filaments, and the velocity of the moving filaments. The functional capability of a muscle depends on the torque that it can exert, which is influenced both by its contractile properties and by the location of its attachments on the skeleton relative to the joint that it spans.	对于一个特定的肌节排列，肌力大小取决于 Ca^{2+}对横桥的激活，粗细肌丝之间的重叠度以及肌丝移动速度。肌肉的功能取决于它能够产生的扭矩，这个扭矩受到两个因素的影响：肌肉的收缩特性；相对于其跨越的关节，肌肉附着在骨骼上的位置。
To perform a movement the nervous system activates multiple muscles and controls the torque exerted about the involved joints. The nervous system can vary the magnitude and direction of a movement by altering the amount of motor unit activity, and hence muscle torque, relative to the load acting on the body. Increases in movement speed, however, enhance motion-dependent interactions between body segments, producing unwanted accelerations that must be controlled by the nervous system. Furthermore, the nervous system must coordinate the activity of multiple muscles to provide a mechanical link between moving body segments and the required support from the surroundings. The patterns of muscle activity vary substantially between movements and often include strategies that augment the work capacity of muscles.	为了进行一个运动，神经系统激活多个肌肉，并控制涉及关节所施加的扭矩。神经系统可以通过改变运动单位的激活数量，从而改变肌肉扭矩，与作用于身体的负载相对比，来调节动作的大小和方向。然而，随着运动速度增加，身体各部分之间运动时的相互作用也会增强，这会导致不必要的加速度，产生必须由神经系统控制。此外，神经系统必须协调多个肌肉的活动，以提供一种机械耦合，将移动的人体环节与周围的环境支持联系起来。进行不同的动作，肌肉活动的模式有很大的差异，通常包括增强肌肉作功能力的策略。

注：文中划线部分为报告正文中所选取的译例。